Minutes of proceedings of the Institution of Civil Engineers

Institution of Civil Engineers (Great Britain)

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JAMES FORREST,

SECRETARY TO THE INSTITUTION OF CIVIL ENGINEERS

1860—1896.

From a Photograph by Messrs. W. & D. Downey, London. (1887)

MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH OTHER

SELECTED AND ABSTRACTED PAPERS.

VOL. CLXVI. 1905 c.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. INST. C.E., SECRETARY.

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CORRIGENDA.

Vol. clxi, pp. 223 and 247, in the footnote, *for* "vol. cxlii, p. 460" *read* "vol. cxxxvi, p. 321."
„ clxv, p. 156, last line, *for* "ore-mains" *read* "Hodbarrow Mains."
„ „ p. 165, l. 8, *for* "weeds" *read* "seaweed."
„ „ p. 170, l. 10, *delete* "1 inch."
„ „ p. 178, l. 27, *delete* "the" *before* "crossing."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1905-1906.—PART IV.

SECT. I.—MINUTES OF PROCEEDINGS.

3 April, 1906.

Sir ALEXANDER RICHARDSON BINNIE, President, in the Chair.

The Council reported that they had recently transferred to the class of

Members.

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STEPHEN MITCHEL DIXON, M.A., B.A.I. (*Dublin*).
CHARLES HENRY GOTT.
FREDERIC WALTER HODSON.
WILLIAM RICHARD VICTOR PRITTIE PERRY, M.A.I. (*Dublin*).
JAMES STEVENSON SMYTH, B.E. (*Royal*).
JOHN THOMPSON.

And had admitted as

Students.

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ARTHUR ALDRED.
LOUIS GEORGE ALLISON.
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ERNEST FRY.
REGINALD GADSBY.
BURNETT GILROY CRAUFURD GARD'NER.
EDWARD ROYSTON GEORGE.
ROBERT GILCHRIST.
HAROLD COLDBECK GILL.
REGINALD GLANFIELD.
THOMAS ALFRED GRANGE.

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ERSKINE PHILIP WATSON.
ROBERT WEIR.
CHARLES EDWARD WHITE.
REGINALD AYTON WINFIELD.
GREENWOOD WOODMAN.
CHARLES GORDON WOOLWAY.
HENRY NORMAN WORTH.
JOHN ARMOUR WOTHERSPOON.

The Scrutineers reported that the following Candidates had been duly elected as

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ALEXANDER WANNAN DONALDSON.

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HEDLEY ANDREWS.
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Petrie Yewdall.
Andrew Reginald Young.

Associates.

Ernest Edwards Jones.
Thomas Mason.

(*Paper No. 3602.*)

"The Harbours of South Africa; with Special Reference to the Causes and Treatment of Sand-Bars."

By Cathcart William Methven, M. Inst. C.E.

The subject of this Paper is one with which the Author has been closely identified in South Africa during a period of 17 years since 1888. For the first 7 years of that period (1888–95) he was in charge of the Natal Harbour Works at Durban as Engineer-in-Chief. Subsequent events led to his examining and reporting upon practically the whole of the harbours on the South-East African coast, from the Cape to Delagoa Bay; and he ventures to hope that the following information in regard to these harbours so far as already developed, and to some which are still in their natural condition but whose possibilities he has had to investigate, may be of interest to the Institution. Owing to the wide scope of the subject, the Author must confine his remarks principally to the physical features affecting the harbours referred to, and to some of the problems that arise in dealing with the bars which so seriously obstruct nearly all the harbours on this sandy coast. Special reference will be made to the harbour of Durban in Natal, as an example of what it is possible to achieve by working on natural lines, and of the difficulties which beset all attempts to coerce Nature.

The construction of harbours, under the almost insuperable difficulties which often present themselves on the exposed sandy coast of South-East Africa, is of supreme importance to the country, which possesses very few naturally sheltered sites capable of being utilized.

The South-East African Littoral.

In connection with the following description of the littoral between Cape Town and Delagoa Bay the Author is indebted to Mr. William Anderson, the Government geologist in Natal, for some valuable information. One remarkable feature is the absence along the South-

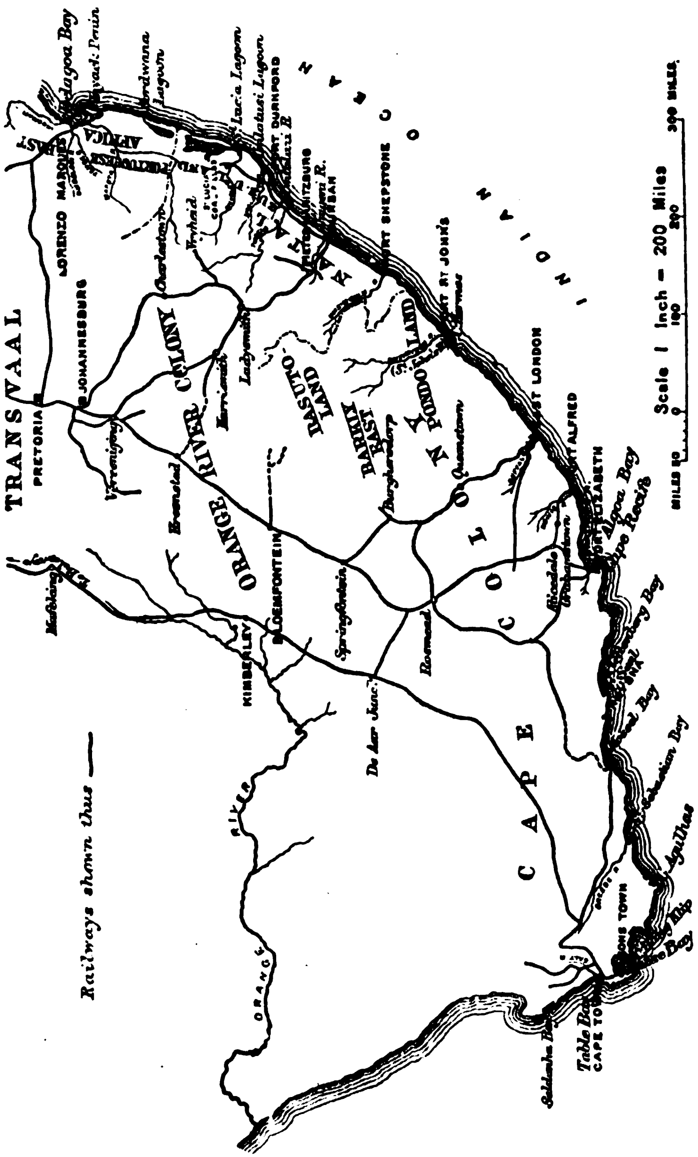
East African coast, between Cape Town and Delagoa Bay, of deep-water indentations forming natural sheltered harbours. Such embayments as do exist lie between False Bay and Algoa Bay. North of this, although there are small rivers and some lagoons, presenting certain possibilities as harbours—only to be realized, however, by considerable expenditure—there is not a single well-sheltered deep-water indentation on the coast-line the whole way to Delagoa Bay. Even False Bay, which faces nearly south and is almost square in form, has an entrance between the Cape of Good Hope and Cape Hang Klip about 25 miles wide; and as the depth of the indentation is about the same, and the width is practically uniform all the way in, heavy seas run into it. The only comparatively sheltered spot in False Bay is Simon's Bay, where the Admiralty docks are in course of construction. Going eastward along the coast, a striking feature is that every bay has a rocky promontory on its western side (*Fig. 1*): it is only immediately under these promontories that any shelter exists, and there only from south-westerly gales. There are apparently two main reasons for this, and for the absence of depth both of indentation and of water. The first is that the hard quartzite rocks which now protrude on the western sides of these embayments, and which resist marine erosion fairly well, cover softer rocks below, which to the east are more exposed to erosion by south-easterly seas, which scoop out the bays in the form shown on the map. The second reason is that, unlike some other parts of the world, where gradual sinking of the coast has submerged deeply-eroded valleys, thus forming deep and sheltered natural harbours, there is clear proof that, within recent geological times, the coast of South-East Africa had been gradually rising.

The effect of marine denudation in producing irregularities in the sea-bed is much more limited than that of atmospheric denudation. It is therefore only under very exceptional circumstances that depressions occur in the sea-bed which are sufficiently extensive and enclosed to become good natural harbours. This is no doubt one of the reasons why, on a rising coast-line, deep depressions which would form good natural harbours are rarely met with; and the Author thinks that, with the exception of Cape Town, Durban, and Delagoa Bay, and possibly Port Elizabeth in Algoa Bay, South-East Africa will have to look for her harbours chiefly to the rivers. Many of these, with the lagoons generally found at their mouths, have features which modern engineering can deal with efficiently, though unfortunately, in every case with which the Author is acquainted, they are such as to involve constant dredging.

Northwards of Algoa Bay the coast becomes less precipitous and

rocky, and long stretches of sandy beach and dunes occur. At

Fig. 1.



SOUTH AFRICA. REFERENCE MAP.

St. John's River, the Table Mountain sandstones are again met with, and form the rocks of this district. The extremely picturesque

chasm through which the river enters the sea is probably due largely to the presence of faults in these sandstones, its sides forming two great walls, which rise to a height of about 1,200 feet.

The southern coast of Natal is equally destitute of deep-water sheltered inlets; and the first possible harbour is the mouth of the Umzimkulu River, known as Port Shepstone. Between this point and Durban the rocks of the coast consist of a series of small outlying spurs of Table Mountain sandstones, granites, Ecca shales, and glacial conglomerate, with a fossiliferous calcareous sandstone from Isipingo to the bluff at Durban, the age of which is not certain, which is also met with at Algoa Bay, and elsewhere along the coast. All along the Natal coast there are immense stretches of sandy beach and dunes, with small rivers at frequent intervals, and up to the Umlalazi River, about 18 miles north of the Tugela, where the whole aspect and the physical geology of the coast change entirely. The littoral becomes slightly undulating, covered with great depths of sand, and fringed along the coast-line by ranges of dunes, often several hundred feet in height. The older rocks inland are not exposed nearer to the coast-line than about 5 miles, at Port Durnford, increasing to 50 miles on the Portuguese border. This immense area contains many large lakes and lagoons, some salt and some fresh. St. Lucia Lake is about 50 miles in length, including its outlet, by 10 miles in width, and has an average depth of only 4 to 10 feet. It is separated from the sea by a long strip of land, consisting chiefly of dunes covered with vegetation and bush, 2 to 4 miles in width.

Wherever rocks are exposed, either on the coast, at the margins of the lakes or lagoons, or elsewhere, they are in all cases of upper cretaceous or later age, affording conclusive proof of the geologically recent elevation of the coast. It is the old sea-bottom, raised gradually into its present position as a land surface: during its elevation it was not perfectly level, and the hollows were subsequently occupied by the present lakes and lagoons. These as a rule are at or near the mouths of the rivers, and therefore either among or just inside the dunes of the coast-line. Among them are the lagoons at the mouth of the Umlatusi River, the outlet from St. Lucia Lake, and the Sordwana lagoon. About 60 miles north of this latter point Delagoa Bay is situated. Further evidence of the gradual elevation of the littoral, even along the rocky coast-line between Port Elizabeth and Cape Town, is afforded by the raised beaches found at considerable elevations, as for instance at, and in the neighbourhood of, Mossel Bay. There is also a very well-marked beach at the end of the bluff at Durban, about 20 feet above the level of high water, the

mollusca of which show that its elevation has taken place within geologically recent times.

Table Bay.—The breakwater sheltering the harbour of Table Bay, Cape Town, which was designed by the late Sir John Coode, Past-President Inst. C.E., and begun in 1860, is now about 3,600 feet in length, and consists of a rubble mound, to which a concrete superstructure is now being added. It affords shelter from the north-westerly seas, which, entering the wide opening of the bay, about 20 miles across, would render its southern recess, where Cape Town stands, quite unsafe for shipping without this protection (*Fig. 2*). It has not been practicable to obtain dynamometer records here of the force of the waves, on account of the sea-slope of the rubble mound having assumed a varying inclination of 1 in 2½ above high water, 1 in 5 to 1 in 7 to 15 feet below low water, and 1 in 1½ lower down. This causes the seas to break so far back that it is of no use to place an instrument there. Waves, which were estimated to be 25 to 30 feet high from trough to crest, have, however, been observed passing under the breakwater staging.

The two existing docks, one of 64 acres with jetties projecting into it, and the other of 8½ acres, are situated immediately under the lee of the breakwater. In order to afford more complete shelter to the entrance to the main dock, a slight southerly bend was given to the last 1,300 feet of the breakwater (*Fig. 2*). With the growing requirements of traffic the present docks have become insufficient, and still more shelter is required. Having been invited by the Government, in 1902, to visit Cape Town for the purpose of reporting to them on the reclamation of the foreshore of Table Bay between the docks and the mouth of the Salt River, a distance of nearly 3 miles, the Author was requested by the Harbour Board to consider, at the same time, and to report, in conjunction with the Board's General Manager and Chief Engineer, Mr. Hammersley Heenan, M. Inst. C.E., on the question of future dock-extension. This led to an extensive scheme, which consists mainly of the doubling of the south pier of the present docks; the extension of the south pier elbow southward to the new entrance (*Fig. 2*), between which and Craig's Battery, on the south-east side of the bay, it is proposed to construct a concrete-block mole about 7,000 feet in length, thus enclosing about 431 acres of the bay immediately in front of Cape Town; and the construction of a central jetty opposite the foot of Adderley Street, about 2,700 feet long and 375 feet wide. The main object of constructing this jetty is, that owing to its central position, it will afford shelter from the strong south-east winds, peculiar to Cape Town, to the whole of the enclosed harbour lying between it and the south

pier, where further jetties can be constructed as required, each with its separate railway-sidings.

In 1883 the late Sir John Coode recommended an extension of the breakwater, as indicated in *Fig. 2*; and this recommendation was endorsed by Messrs. Coode, Son and Matthews in 1895.[1] The Author and Mr. Hammersley Heenan have also recommended the

Fig. 2.

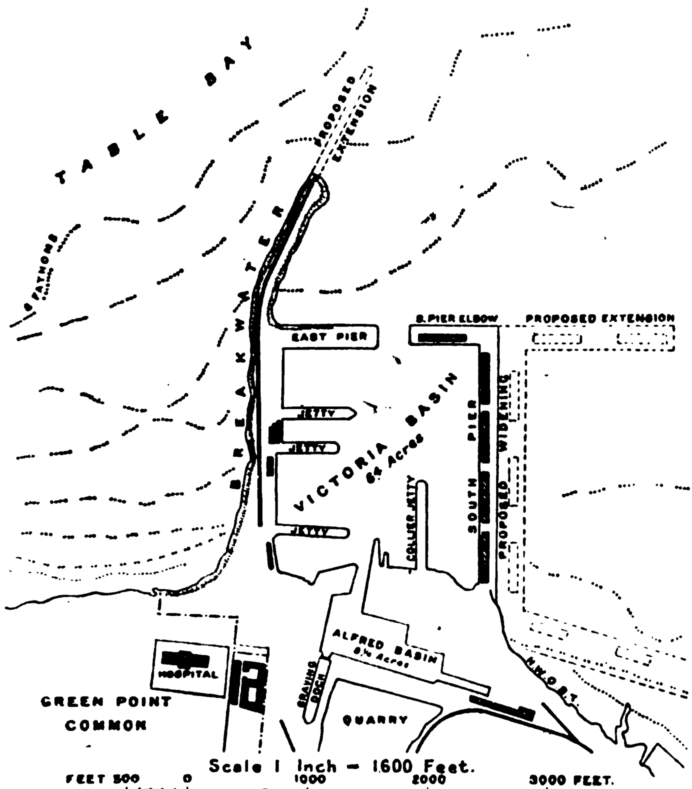


TABLE BAY HARBOUR.

extension of the breakwater on its present line for 1,000 feet, to afford more shelter, both to the present dock-entrance, and to the entrance to the proposed main harbour within the mole. The cost

[1] Table Bay Harbour. Report by Messrs. Coode, Son and Matthews on the Existing and Proposed Works, Cape Town, 1895. (Copy in the Institution Library.)

of this scheme, including the reclamation of the foreshore between a point 1,300 feet south of the proposed Adderley Street pier and the present docks, but without the intervening jetties, is estimated at £3,561,757. This also includes the construction of a quay-wall along the face of the reclamation, to give berthage 20 feet deep at low water. It was decided to give this shallow-draught berthage along this line, on account of the underlying rock which fringes this shore of the bay, the vessels of deeper draught lying farther out alongside the jetties or the south pier. Portions of this scheme are now in progress. With the vast territory which is now thrown open for development, and for trade with other parts of the world, and considering the somewhat limited capacity of the other Cape ports and of the railways which serve them, it may be confidently predicted that, even with all the disadvantages of geographical position as regards the Transvaal Colony and Rhodesia, Cape Town will command for many years a large inland trade; and, as a port of call, it must steadily grow in importance as commercial relations between the Cape and Australia extend.

The following statistics illustrate its growth, even within a few years.

Cape Town.	Customs Revenue.	Imports.	Exports.
Year.	£		£
1895	577,605	3,343,105	8,482,441
1904	976,498	8,080,558	16,745,470

EMBAYMENTS OF SOUTH-EAST LITTORAL.

Reference has already been made to the remarkable absence of deep, sheltered bays on the south-east coast of Africa. The bays which do exist, though partly protected by their western headlands from south-westerly seas, are fully exposed to seas from south to south-east. For this reason, and also because the back country in their neighbourhood has not yet attained such a condition of development as to warrant the heavy expenditure necessary to create ports in such situations, only Mossel Bay and Algoa Bay have so far been utilized to any extent. It appears probable from the Admiralty chart that the construction of a harbour at the embouchure of the Breede River in St. Sebastian Bay might not be found impracticable, though the situation is very exposed. At the present time, however,

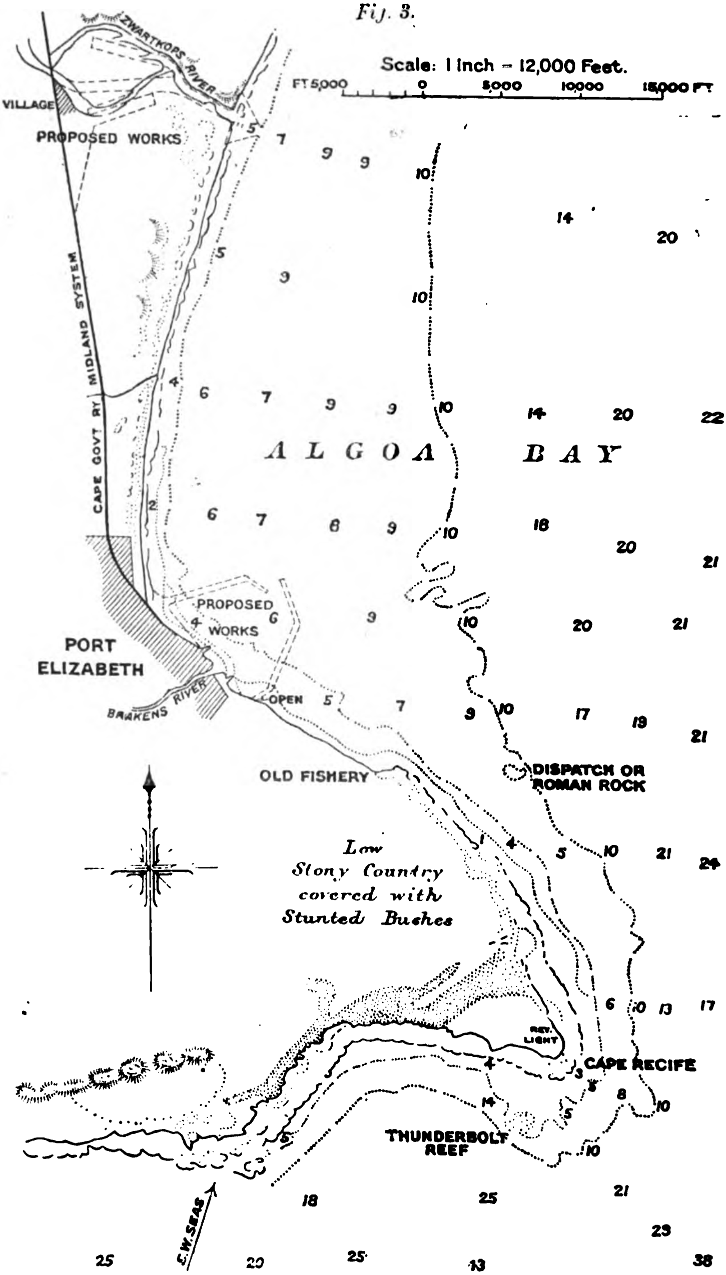
on the stretch of coast so exposed to severe storms between Cape Town and Delagoa Bay, a distance of about 1,200 miles, no harbour of refuge exists for which a vessel can make in stress of weather with the assurance of a safe entry—a thing which, with a very large and constantly increasing ocean traffic, is more and more needed.

Plettenberg Bay was examined by the late Sir John Coode in 1876. In reporting upon it, he stated that it had been frequently spoken about as a harbour of refuge, being naturally protected against all winds between south-east and south-west, and that its peculiar configuration, owing to the deep indentation caused by the promontory, 2 miles in length, terminating at Cape Seal, and the good depths and anchorage to the north of this projection, rendered it well adapted for such a harbour; whilst there was abundance of good material on the spot. On the other hand, he pointed out that its geographical position is by no means as favourable as that of Mossel Bay, which he stated was much more resorted to by sailing vessels for shelter when met by heavy westerly and north-westerly winds in trying to get round Cape Agulhas, a difficulty by no means uncommon in the winter season. Gales along this coast are almost invariably more from the eastward than southward of south-east; and therefore, unless actually embayed, no vessel need go on shore in such gales anywhere west of Cape Recife at Port Elizabeth.

At Mossel Bay Sir John Coode found that the bottom was subject to considerable changes by shoaling and deepening, and that great caution would be necessary in laying down any sheltering works. The Author visited this bay in July, 1902, in order to report to the Government on certain works which had been executed and were in progress. While it would be possible to construct works there, which would form a harbour of considerable capabilities, its serious exposure to heavy rollers from the south-east, and its general contour, do not, in his opinion, recommend it as a good site for a harbour of refuge. There is a thriving community at Mossel Bay, and about 6,500 square miles of rich agricultural country to be served at the back of the port (equal to nearly twice the area of Wales), which would probably be doubled if the railway were extended to Oudtshoorn and Nels Poort.

Algoa Bay.—The last of this series of embayments, proceeding north-east, is Algoa Bay or Port Elizabeth (*Fig. 3*), which in 1820 was a small fishing-village with a military post, and to-day is one of the most important ports of Cape Colony, with a population of 46,626 persons, of whom 23,782 are Europeans. The shelter afforded by Cape Recife from southerly to south-westerly seas is very con-

Fig. 3.



ALGOA BAY.

siderable; but the bay is open to south-easterly gales, which frequently blow with great violence, and have more than once caused serious casualties to shipping at anchor in the roadstead. Yet in spite of all these difficulties, and often in the face of very rough weather, the whole of the landing of goods at Port Elizabeth has been carried on in the earlier days by means of surf-boats and sailing barges landing on the beach, and later by a system of lighterage between the vessels in the open roadstead and iron jetties projected from the shore and furnished with railway-communication and hydraulic cranes. The remarkable strides in commercial prosperity which this port has made, in spite of the landing-difficulties, are shown by the fact that in 1893 the customs revenue was £1,097,193, and in 1904 the value of the imports was £6,855,729 and of the exports £2,044,508.

Many proposals have been made with a view to remedy the want of sufficient shelter from the south-east. Before 1870, and therefore before the days of the larger aspirations which now prevail, a small breakwater of timber and rubble stone was erected at the mouth of Baaken's River, an insignificant stream entering the bay through a deep cleft at the western end of the present town. The immediate result of this work, placed at right angles to the shore, was to act as a groyne, arrest the travel of sand from east to west due to the surf-currents, and threaten a serious accumulation of sand on the part of the beach where landing- and loading-operations were carried on by means of surf-boats. In consequence, the work had to be removed; but it has left behind it a valuable record of the danger of running out solid works at right angles to the coast, without due consideration of their effect in arresting the in-shore drift, and of the means of dealing with it, if such a work is essential.

The open jetties on iron piles which were advocated and carried out under the advice of the late Sir John Coode have the advantage of presenting no obstacle to the free passage of sand between the piles; so that three of these jetties have now been used for a number of years, without producing any change in the foreshore in front of the town: but it is impossible for any but very small vessels to lie alongside them, and then only in quite calm weather. Sir John Coode also made a proposition which was novel at the time, and was specially designed to meet the necessity of non-interference with littoral sand-travel, namely, to construct an open iron viaduct from the shore seaward, for a distance of about 3,000 feet, terminating in a solid breakwater nearly at right angles to it, and about 2,000 feet in length, with jetties projecting shoreward from it under its lee, at which vessels were intended to lie. This work

was fortunately never carried out, for, though the idea was an ingenious one, it is practically certain that vessels could not have lain alongside such a breakwater or jetties except in the smoothest weather. As the trade of the port grew, the necessity for complete shelter of some kind made itself more and more apparent, until it has now become an absolute necessity, if Port Elizabeth is to hold her own with other ports on the coast, where vessels can lie in security alongside sheltered wharves. Two important schemes are therefore now under consideration (*Fig. 3*): one to enclose a large harbour of 800 acres by means of two great breakwaters projected from the shore; and the other to open up the Zwartkops River, which runs into Algoa Bay about 5½ miles to the north of the railway-terminus in the centre of the town, thus providing a sheltered harbour furnished with the ordinary wharves, sheds, etc., and providing room for indefinite extension in the future. The first of these schemes was proposed in February, 1897, by Messrs. Coode, Son and Matthews, and subsequently formed the subject of a Report[1] by Sir John Wolfe Barry, K.C.B., Past-President Inst. C.E., Mr. Wm. Matthews, C.M.G., Vice-President Inst. C.E., and Mr. A. G. Lyster, M.Inst. C.E., in 1905, the cost being estimated by them at about £3,100,000.

The opening up of the Zwartkops River, upon which the Author was asked to report, would provide Port Elizabeth with a completely sheltered harbour, free from the serious problems involved in the other scheme, and at a cost which, to begin with, need not exceed £1,500,000, while it would be capable of indefinite internal extension. There are, however, important questions in connection with it, as to the disturbance of vested interests in Port Elizabeth; and this proposal is, like the other, under consideration.

The Zwartkops River is tidal for some miles, and has a tidal volume, as ascertained by careful tachometer measurements, of about 4,500,000 tons, which would be somewhat increased with the opening up of the river-mouth by dredging and works. The river is barred by sand just outside its mouth; and the minimum depths on the bar are only 6 inches to 2 feet at low water of spring-tides, which have a range of 5 feet 5 inches. The railway crosses the river about 2½ miles above its mouth. On the north bank, between the railway-bridge and the sea, is the sandy range of low-lying hills, known as the Zwartkops, descending abruptly to the river-bank, and leaving little room for quayage on that side, except for about a mile below the railway.

[1] See "Port Elizabeth, Algoa Bay: Proposed Harbour Improvements. Report of Commission of Engineers, 1904-5." (Copy in the Institution Library.)

Between the subsidiary channel, or backwater, on this side, and the main or southern channel of the river, there lies a considerable area of slob land, intersected by small channels, and overflowed 6 to 9 inches by high water of spring-tides. On the south side of the river, the slob lands are of very considerable extent, and lie at a general level of about 9 inches below high water. These slob lands would form a very valuable area for reclamation with the spoil dredged from the river, and afterwards for quayage. Extensive borings and probings have proved that there is no obstruction of rock in the bed of the river, and that an outcrop of calcareous sandstone, on the north side of the entrance near the bar, dips rapidly to the southward and disappears. It is not anticipated, therefore, that any obstacle will be presented to dredging on the bar.

There are no shingle beaches along the coast of South-East Africa between Cape Town and Delagoa Bay, though at a few spots there are accumulations of gravel, sand, and shells. The entire coast-line, where not precipitous and rocky, is sandy; and, so far as the Author knows, the sea-bottom off the coast is for the most part also sand. Between what is brought down by the river in flood during the heavy sub-tropical rains, washed in from the sea-bottom, and eroded both by the sea and by the winds from the vast accumulation of dunes which line the seaboard, the sand-supply is continuous and on a vast scale. The variations in its movements, also, are infinite, depending mainly on the direction and strength of the seas, and on local conditions. The Author found the travel of sand in Natal and elsewhere to be, as a rule, from south to north, the prevailing seas acting obliquely to the coast-line in that direction. There is also on the Natal coast a northerly littoral current, counter to the Mozambique current, which flows southward 5 to 10 miles out at sea. This littoral current has not generally sufficient velocity to transport sand of itself, unless in suspension; and the main cause of the almost continuous travel of sand along the exposed parts of the coast is the action of the seas, especially between low- and high-water marks, and the currents set up between the same limits, and for some distance seaward of them, by the heavy surf which constantly sets in upon these shores. That the movement of sand by the waves is effected at considerable depths is proved by the fact that in 1891 the Author found that sand from the inner bay or lagoon at Durban, deposited by the dredgers about 1½ mile out to sea, and in 60 feet of water, was washed ashore in large quantities in the neighbourhood of the Durban breakwater. Sometimes, during the continuance of off-shore winds, vast sand-accumulations take place along some parts

of the coast, which, on the occurrence of a heavy easterly sea, are cut out by the waves, and drawn back into the bed of the ocean, to be later on largely returned. During such on-shore seas, should the littoral current be running strongly, sand held in suspension by the action of the breakers can be observed travelling northwards in large quantities well seaward of low-water mark; and this sand-travel becomes even more marked if the seas become more southerly, and therefore more oblique to the coast-line. During such periods of heavy littoral drift, large quantities of sand were conveyed by the littoral and surf currents round the end of the Durban breakwater, and deposited in the area under its lee, where, owing to the shortness at that time of the northern work, there was comparatively slack water. The accumulation then rapidly extended across the entrance, blocking it up, and forcing the tide over to the north.

Another important phase of littoral drift, on the South-East African coast, is that due to the wind, which lifts the finer sand from the slopes of the dunes along the upper side of the beaches, and sometimes from sand-flats behind them. This was well exemplified at Port Elizabeth, where a great sand-drift on the Recife peninsula proved a serious source of trouble to Algoa Bay, during the prevailing westerly and south-westerly winds. Planting, however, was resorted to, after spreading town refuse over the sand; and the result has been very satisfactory, as described by Mr. Hammersley Heenan in a Paper[1] on the Harbour of Algoa Bay.

At the request of the Port Elizabeth Harbour Board, a very extended investigation of the movements of sand was made by the late Mr. Allan Brebner, M. Inst. C.E., in 1899, on the shore of Algoa Bay, between the Zwartkops River and Cape Recife, in order to ascertain to what extent this might be likely to interfere with the works which it was proposed to project into the bay in front of Port Elizabeth. Up to that time the extent of any such sand-travel was purely a matter of conjecture. The work was begun by Mr. Brebner in June, 1899, and was carried on continuously over a period of 1 year and 8 months. After his investigations Mr. Brebner expressed the opinion that, though there was a tendency for drift-sand to move northwards along the west shore of Algoa Bay, there was no continuous or regular travel or drift of sand in that direction, either from wave-action or from wind, so as to cause an accumulation of sand on the south side of a breakwater built on the west shore of the bay, beginning above high-water mark, and extending seaward at any angle convenient for the formation of shelter within it. He

[1] Minutes of Proceedings Inst. C.E., vol. cxxx, p. 263.

also held that in a harbour enclosed by two such breakwaters, one of which was left open, at its shore end, by constructing a viaduct about 1,000 feet long, the sand carried into the harbour in suspension in the breakers would not exceed about ⅜ inch per annum. He also came to the conclusion that there were no littoral currents in the bay to interfere with the construction of works there. Sections, taken periodically, also appear, he says, to have shown that sand is "moved and stirred" by the waves at depths of 30 feet; that between depths of 4 feet 6 inches and 10 feet at high water, variations occur in the bottom, over a period of 8 months, to the extent of 5 feet 6 inches; and that the zone of maximum disturbance of the sand on the bottom is at low-water level. If Mr. Brebner is right in these conclusions, then any works at Port Elizabeth will be free from one great engineering difficulty; but the Author holds strong opinions as to the danger of sand-accumulations outside works of this nature, and on such a scale, built across the littoral drift on this coast, even if the precaution be taken of making an open viaduct connection with the shore: and especially is there danger if, as is proposed in this case, the northern arm were a solid work.

The principal subject with which the Author has to deal in the present Paper is the sand-barred harbours on this coast; and the Zwartkops is the first river met with, going northwards from the Cape, where this difficulty has been fully investigated. Between here and Delagoa Bay there is no harbour—nor any site proposed for a harbour—which has not, in its natural state, either a sand-bar, or a solid beach across its mouth. Before describing some of these river-mouths, and what has been done to open them permanently, the causes of the formation of these bars must be made clear.

Formation and Treatment of Bars.—Great differences of opinion have always existed as to the precise cause of the areas of shallow water which are so often found at the mouths of rivers in this and other countries, and which, forming a serious obstacle to their navigation, have been termed bars. They may be formed under a great variety of circumstances, and many theories have been propounded to account for the phenomenon: *e.g.*, a deposition of material where the outgoing ebb-tide meets the incoming flood; the deposition of material brought down by the river, where the velocity of its current is checked by the seas or tide, or by its entry into the larger area of the ocean, or by the inflowing tidal water, which, on account of its higher specific gravity, meets and checks the lower stratum of the outflowing fresh water of the river and causes deposition; or the want of a sufficient volume of backwater, and therefore of scouring-power. There are also bars composed of various materials, such as

alluvial deposit brought down by the river from the uplands, shingle, sand, clay, or even rock, for the existence of which there may be a variety of reasons.

On the south-east coast of Africa, every river and lagoon that the Author has examined is barred by sand, which is usually of a loose, free character, and is sometimes very light on account of the presence of large quantities of finely comminuted shelly matter. In most of the small rivers this sand accumulates during the absence of floods, until it forms a beach across, and entirely closing, the river-mouth: here it remains until broken through and swept away by the next flood, after which it again accumulates rapidly. Such is generally the case when the tidal compartment of the river is of small extent. Where the tidal compartment, often in the form of a lagoon, is of sufficient extent, the inflowing and outflowing tidal waters frequently afford a scour strong enough to prevent the entire closing of the mouth; but in all cases the depth over the shallowest part of the bar, or partially submerged beach, is very small—frequently not more than a few inches at low water. A characteristic feature of many of the rivers is that often 3 to 15 miles up from the mouth, as in the case of the Kowie River, Port Alfred, the Buffalo River, East London, and the Umzimvubu River, Port St. John's, a tidal compartment is found, varying in width up to perhaps 800 or 1,000 feet, or even more in parts, and narrowing sharply at its upper end. Here it generally receives a rapid, clear stream, often of quite insignificant proportions, except in times of flood, when, owing to the quick rise of the back country, and the occasional heavy sub-tropical rains, sudden and heavy floods come down. The result of these floods is usually to clear out any deposit of sand brought within the mouth by the seas and tides, and to sweep away the bar for a time. This often occurs, especially in the case of the Umzimvubu River, to a considerable depth. A gradual silting-up, or re-formation of the bar, then takes place, at a rate depending on such circumstances as weather, etc. Little change takes place, as a rule, in the tidal compartment itself from these occasional floods. The matter brought down in suspension is rapidly swept out to sea; and practically no detritus or silt is brought down by the rivers at any other time. In the event of the opening up of the rivers for harbour purposes, and the consequent enlargement of the normal sectional area of the tidal compartment, there is little tendency to silt up again, except in the immediate neighbourhood of the bar, where shoaling frequently occurs by the deposition of sand from outside.

Since 1888 the Author has closely studied the river-mouths on this coast, and he has no hesitation in ascribing the bars which

obstruct them to the action of the waves on the sandy bottom of the ocean immediately in front, and on the accumulations of sand along the beaches on one side or the other. These, with the aid of the surf-currents, provide a constant supply for the seas to act upon and heap up. There are, in fact, two principal factors at work; the seas which constantly endeavour, by sweeping in sand, to form a beach across the mouth; and the outflowing tidal waters, sometimes greatly augmented in time of flood, which strive to counteract this by scouring away the deposit. In the case of the smaller rivers, this usually ends in a triumph for the sea. In the case of the larger rivers, the beach remains partly submerged, with only a narrow channel—or at all events a very shallow and unstable one—through or over it at low water. The form assumed by these bars is sometimes roughly an arc of a circle, which may become distorted, and approach nearer to the shape of a horse-shoe, with its apex to one side or other of the entrance. This is generally the result of special circumstances, *e.g.*, a somewhat oblique direction of the seas to the mouth, the existence of a rocky projection causing a deflection of the outflowing tide which finds its level in the ocean by the line of least resistance, or the littoral currents.

At the London International Maritime Congress in 1893, Mr. A. G. Lyster, the Engineer-in-Chief to the Mersey Docks and Harbour Board, gave a very clear description of the primary cause of the curved form assumed by sand-bars.[1] Supposing the volume of water in the river-channel to be constant as far as its outlet, immediately it passes into the sea it spreads out laterally, causing a decrease in volume and velocity directly in front of the outlet, which produces a gradual rise in the bottom seaward, and also at the sides. This results in the formation of a ridge or mound along the curved line forming the intersection of the side slopes of the channel with the outer slope of the bank, which constitutes a river-bar. Such a bar occurring on the sloping sea-bottom at the mouth of a river is liable to great distortion, depending on the various factors at work which tend to effect it, such as the conformation of the outlet of the river, the existence of promontories on either side, waves, littoral and surf currents, etc.: but the general curved form can often be traced.

Lagoons.—The same formation usually occurs at the outlets of lagoon harbours, though in these cases there is generally a variation in the circumstances leading to the formation of the bar. In the larger lagoons on this coast which the Author has investigated

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[1] "International Maritime Congress, London, 1893, Section I, Harbours and Breakwaters," p. 62.

with the view of determining their adaptability as harbours, such as the Umlatusi lagoon and that at the mouth of the St. Lucia and Umvolosi rivers in Zululand, where everything is still in its wild, natural condition, the mouths or outlets to the sea are liable to, and frequently undergo, complete changes in position; and the outlet which may be here to-day, in a few months' time, or even much less, may be a mile farther along the coast, in either direction. No doubt such changes occurred at one time in the lagoon now forming the Port of Durban.

It is to the class of river already described, and to lagoons, that South Africa will have to look for many of its harbours in the future. Indeed, in 1903 the Author recommended the Umlatusi lagoon in Zululand to the Government of Natal, as the most promising site for a port on the Zululand coast. It is typical of the lagoons of the country, and is situated about 45 miles northward of the mouth of the Tugela River. The lagoon at Durban, known as Durban Bay, in its original state, before the construction of any engineering works, and that at the mouth of the St. Lucia River in Zululand, are examples of the same type, as are also, on a much smaller scale, the lagoons within the mouths of several of the smaller rivers along the coast. The area of the Umlatusi lagoon at high water is 7,788 acres. It lies amidst an extensive area of flat, swampy land; so that when a permanent channel between it and the sea is opened up, of sufficient sectional area to admit of the free inflow of the tide, this area will be increased to probably not less than 10,300 acres, or more than twice the high-water area of Durban Bay. It has also the advantage over Durban Bay that, whereas in the latter the proportion of sandbanks above the level of low water of spring-tides is about 3,830 cubic yards per acre, in the case of the Umlatusi lagoon it is only about 450 cubic yards per acre. In other words, owing to the height of the sandbanks in Durban Bay above low-water level, the loss of tidal volume at high water of spring-tides is about 3,000 tons per acre; whereas at Umlatusi this only amounts to 347 tons per acre. Owing to the small low-water sectional area of its outlet to the sea, the lagoon never fills to high-water level. It also never empties itself before the rising tide again partially raises its level. The bottom of the lagoon is 1 to 2 feet below low water of spring-tides, with the exception of a few banks here and there. At neap-tides, there is hardly any variation in the water-level of the lagoon; though a heaping up of the water at one end or the other is often observable during strong winds. Simultaneous observations, by means of tide-gauges set at different points of the lagoon, showed that at high water of ordinary spring-

tides, the present tidal volume of the lagoon does not exceed 4,500,000 tons, or about one-fifth of the original tidal volume of the lagoon at Durban. If, however, a new permanent entrance is formed, of sufficient width and depth to allow of the unrestricted ebb and flow of the tide over its full range of about 6 feet, the tidal volume at Umlatusi will be increased to probably not less than 61,000,000 tons, or about 2½ times the original tidal volume at Durban. This, when works are constructed, will be of the greatest value as a natural agent in maintaining any future entrance-channel, with such assistance by dredging as may be found necessary. According to the survey the Author made in 1892 of the Durban lagoon, the cubic contents of the sandbanks above the level of low water of spring-tides was about 18½ million cubic yards, whereas at the Umlatusi lagoon they are approximately only 3½ million cubic yards: which shows the comparative loss of tidal volume due to this cause.

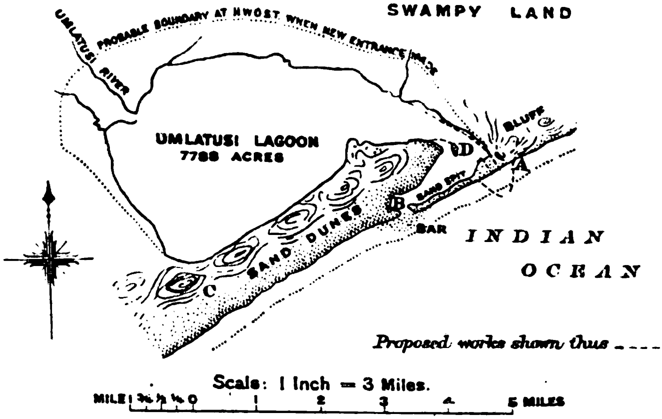
The formation of these lagoons is very well described by Mr. Anderson in his "First report of the geological survey of Natal and Zululand." He says: "Although there are numbers of large rivers which debouch on to the littoral of this coast as permanently strong flowing streams, there is in all cases a bar of sand thrown up by the sea across their mouths. These sandy bars dam back the river-water, until often for miles inland from the mouths it forms deep and often broad waterways, which, but for the presence of the bars, would have formed splendid harbours and waterways for small craft. In many instances large lagoons intervene between the river and its exit into the ocean; but in these cases also a similar and unfortunate sand-bar exists." No doubt in using the term "bars" Mr. Anderson also includes the sand-spits which are found in all cases to lie between such lagoons and the sea, and which, by the joint and persistent action of the waves and the winds, are gradually widened and heightened, until in some cases they become broad and permanent belts of land, covered with sand-hills and eventually by bush and grass, like that lying between Lake St. Lucia and the sea, 1 to 4 miles in breadth, with bush-clad dunes next the sea, frequently attaining a height of several hundred feet.

The sand-spit at Umlatusi lagoon, of much smaller dimensions and more recent growth, extends from the foot of the bluff at A (*Fig. 4*), which is about 100 feet high and of the usual æolian formation, to the point B, where the entrance was at the time of the Author's visit, a distance of about 1½ mile. The growth of this spit, as shown both by its tapering form, and its greater height at the foot of the bluff, as well as by the older vegetation at that end, has been evidently from A towards B. It is almost certain that a

former spit existed between C and D, with the entrance between D and the bluff, and with a bar opposite that entrance in about the position of the root of the present spit, forming the nucleus from which that spit has since grown.

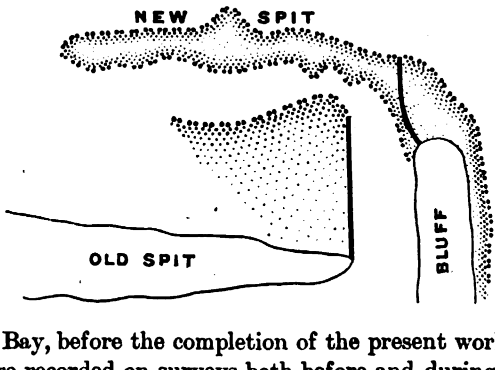
These changes on the South-East African coast, owing to its being

Fig. 4.



in parts surcharged with immense masses of free sand, occur in extraordinarily short periods of time. The Author has, indeed, seen growths of an exactly similar nature, although in a more or less embryo form, make themselves quite apparent opposite the entrance

Fig. 5.



to Durban Bay, before the completion of the present works (*Fig. 5*); and they are recorded on surveys both before and during the earlier stages of those works, as the bluff was practically lengthened by the construction of the southern breakwater.

River Harbours on the South-East African Coast.

Port Alfred.—The mouth of the Kowie River, generally known as Port Alfred, lies about halfway between Port Elizabeth and East London (*Fig. 1*). It has a tidal compartment about 12 miles in length, and varying in width between 250 and 500 feet, with depths of 5 to 10 feet; but in parts it is much deeper. The shores on either side of its mouth are surcharged in immense quantities with loose, free sand, which is easily blown about by the winds. The upper part of the beach, therefore, especially to the west of the river, is lined with dunes of great size; and others are constantly forming along the beach lower down, and shifting their forms and positions. The mouth of the river is fully exposed to gales from south-west round to east. There are no projecting headlands affording shelter of any description; although there is a reef to the south-east of the entrance, known as the Fountain Rocks, which gives a little shelter from easterly to south-easterly gales.

In 1856 the late Mr. James M. Rendel, Past-President Inst. C.E., laid down a plan of training-walls and breakwaters, giving an entrance about 250 feet in width. Mr. Rendel's plan was seriously deviated from, and the entrance was reduced to 170 feet—an unworkable width for any but very small craft. The late Sir John Coode in 1870 advised extensions of the piers at the entrance, which, however, still preserved the old narrow width. In 1877 the trade of the port was increasing, the customs revenue having risen from £3,200 per annum in 1871 to about £30,000 in 1876. It was impossible, however, to realize the depth on the bar anticipated by Sir John Coode, namely, 12 feet at low water; owing to this want of depth, and competition with Port Elizabeth, the trade diminished, and eventually disappeared; and the works, which had cost £250,000, were practically abandoned. In 1900 the Author was requested to examine this river with a view to see what could be done to remedy the then existing state of matters, utilizing the works already constructed to the utmost extent possible. These works, having been constructed with concrete blocks, were in fair condition, though repairs were necessary; but sand had accumulated on the beach southward of the works, until it had entirely buried the western pier for a considerable length under a great slope running down into the channel. A survey showed that the depth just within the piers was only 5 to 6 feet at low water, while just seaward of the piers the depth was 12 to 18 feet at low water. This was very similar to the original condition of the mouth of the Buffalo River at East London after the construction of works, but before the introduction of the sand-pump dredger. The

remedy, namely, dredging, would be the same at Port Alfred were the entrance of sufficient width to admit of the safe working of a powerful plant; but this is not the case. The Author therefore decided that the proper course, so as to utilize the old works, would be to extend the west pier as a curved breakwater sufficiently to cover a new entrance to the east of the existing east pier; to run out a converging east breakwater, starting about 1,000 feet beyond the east pier; and to excavate and dredge a new channel joining the old channel about ½ mile inland. This would give an entrance superior to that at East London, and wide enough to enable powerful dredging-plant to work with safety; while the old channel, and the triangular area enclosed by the new east breakwater, would form efficient wave-traps to reduce the swell entering the harbour.

The port has the great advantage of a large area of flat slob lands lying on both sides. These would be very useful for the excavation of tidal basins—an advantage not enjoyed at East London, where the banks are precipitous.

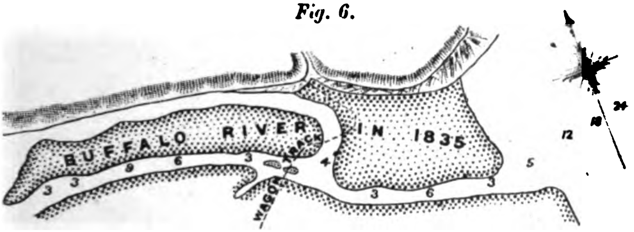
Port Alfred is connected by rail not only with Grahamstown but also with Alicedale, the junction with the main lines leading thence to Kimberley and Bulawayo, and through the Orange River and Transvaal colonies. The distance from Port Elizabeth to Alicedale is the same as from Port Alfred; and therefore, so far as railway communication with the interior is concerned, they are on an equal footing. On the other hand, Port Alfred is 55 miles nearer De Aar Junction than East London, and East London is 55 miles nearer Springfontein than Port Alfred (*Fig. 1*). As compared, therefore, with East London also, Port Alfred is favourably situated, and is in a position, so far as railway-communication is concerned, to compete for a fair share of the inland trade.

The west breakwater at Port Alfred is a concrete-block mound, surmounted by a block superstructure and parapet, and the east breakwater is a rubble mound with a block superstructure. As the seas, even from the south-west, wheel round as their shore-ends are retarded in the shallower water, they approach the works nearly end on, and consequently the works are not so heavily tried as are longer works in deeper water and broadside on to the seas. In nearly all cases, however, on this sandy coast, especially where the works are short, the advance of the contour-lines of deep water caused by their groyne-like action, and the accumulation of sand which, consequently, takes place in the external angle of the work with the shore, cause the waves to break well back from the works, and to become waves of translation long before they reach them; so that the impact of the waves is much less than in cases where oscillatory waves break

suddenly in deep water right on to the works on meeting the abrupt decrease in depth due to the foundation mound.

East London.—The Buffalo River, at whose mouth is the port of East London, is of the same type as the Kowie River, and is exposed to very heavy seas. No accurate observations have been made of the height of the seas in heavy gales; but they have been estimated at 18 to 20 feet from trough to crest. Its tidal compartment is broader, but much shorter than that of the Kowie; and its tidal volume at high water of spring-tides has been calculated to be only a little over 1,000,000 tons. Its mouth, prior to the construction of works, was encumbered by sandbanks dry at low water for a considerable distance inland. Only a narrow channel 2 to 3 feet in depth traversed these banks at low water. In fact, in 1835, and for many years afterwards, there was a wagon-track across the river, as shown in *Fig. 6*, where it is now navigable for large steamships. At the mouth of this river, as at all other river-mouths on this coast,

Fig. 6.



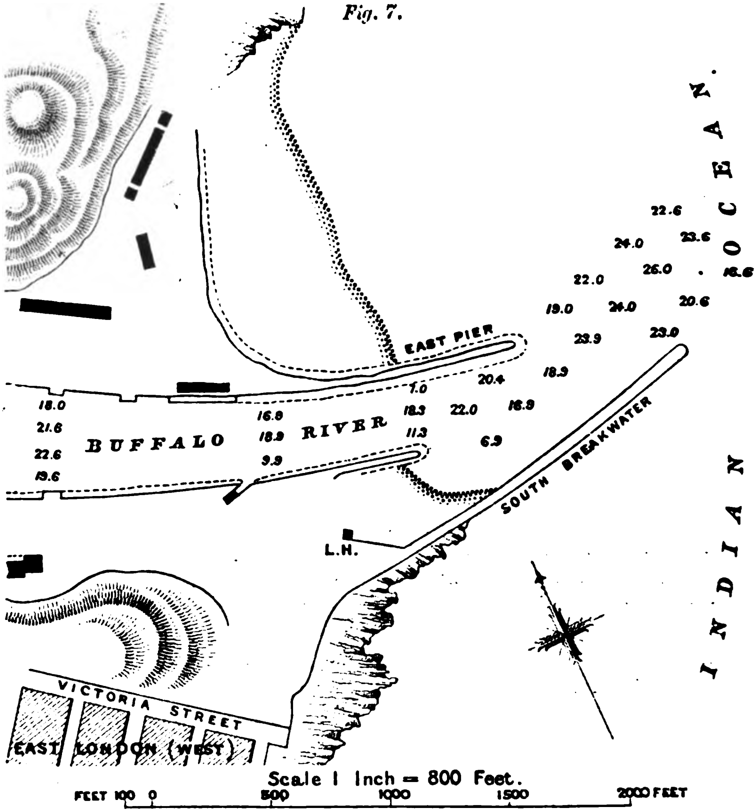
a heavy surf constantly prevails until works are constructed and deepening is effected.

The first serious attempt to improve the river was made about 1870, when the late Sir John Coode examined and reported on it. Some training-walls were constructed shortly after; but it was not until the year 1884 that the present outer piers were completed (*Fig. 7*). These works alone proved insufficient to give the depth of 15 to 18 feet at low water which it was expected to attain over the bar, as the tidal volume was much too small; and a survey made in 1885 shows that the entrance was still so encumbered by shoals that there was a depth of only 2 to 3 feet at low water between the piers. The mistake of the Kowie River was repeated so far that it again proved impossible to gain, in a position exposed to sanding up from outside causes, a depth which the tidal volume could not naturally maintain inside under shelter and through similar material. Too much reliance was also placed on the recurrence of heavy freshets, which used to come down with considerable frequency at one time, but which, for some unexplained cause, ceased almost entirely in

their former volume. One of these freshets, in 1874, swept the inner shoals entirely away, forming depths varying between 14 and 25 feet, the shallower depths being naturally in the broader portions of the tidal compartment; but the outlet soon shoaled up again.

Fortunately, about this time the sand-pump dredger, though invented long before, was brought into prominence by the excellent work achieved by it in Holland; and this appliance has rendered

Fig. 7.



East London.

practicable the opening up of harbours in positions such as those referred to, where previously the attempt would have been hopeless. The "Lucy," a 500-ton sand-pump dredger, was obtained, and, though of comparatively light draught, she cut her way inwards through the shoal water, and afterwards maintained the depths until assisted by more powerful craft.

In 1885, just outside the entrance, there were depths of 15 to 20 feet at low water of springs. Directly the inner shoals were removed by dredging to a depth greater than outside, the bar was practically transferred from just within the piers to the area outside. For a long time the depths there remained about the same, with fluctuations according to weather and to the extent of the sand-accumulations occurring to the west of the breakwater.

During recent years the progress achieved in dredging with powerful plant in an open seaway has enabled the depths outside to be increased to about 20 feet at low water of spring-tides; and East London, with her shipping of to-day, stands, in spite of certain drawbacks as regards the disposition of the entrance-works, a triumph of engineering skill over exceptional difficulties, as well as a credit to the Government of the colony and to the eminent engineer who initiated the works (*Fig. 7*).

The difficulty in the navigation of the entrance, due to the unfortunate position of the east pier, and the contraction of the entrance some little distance within it, is one which will be remedied in course of time. Proposals for its improvement, both by Messrs. Coode, Son and Matthews, consulting engineers to the Harbour Board, and by the Author, are under consideration. Meanwhile a great development of the internal resources of the port is taking place. The western bank is being utilized for additional wharfage; and a high-level bridge is in course of construction, to provide the necessary railway-communication across the river. The Author knows of no other port, situated like East London on a sandy foreshore, exposed to tremendous seas on an open seaboard without any shelter, and hampered within by precipitous rocky slopes on each side, and consequent want of space, where difficulties of so unusual a nature have been successfully overcome.

A powerful sand-pump dredger has now been obtained, with a hopper-capacity of 2,000 tons, and of 1,100 I.HP. Her suction-pipe is 4 feet in diameter; and a good average day's work is the raising, conveyance, and depositing well out at sea, of 8,350 cubic yards of sand. Her shortest time for filling her hopper with 2,000 tons is 30 minutes; and she is able to work in waves 5 to 6 feet in height. The commercial progress of the port is demonstrated by the following figures:—

East London.	Customs Revenue.	Imports.	Exports.
Year.	£	£	£
1895	275,153	2,890,021	760,279
1904	505,558	4,344,315	1,165,938

Port St. John's.—Port St. John's at the mouth of the Umzimvubu River, is a very different case, although here also the precipitous nature of the river-banks, and the extremely broken country to the westward, will present some problems in railway-engineering. St. John's is situated about halfway between East London and Durban, 150 miles south of the latter (*Fig. 1*). The river has a greater discharge than any other on this part of the coast, a course of about 150 miles, and a watershed of 7,375 square miles; whereas the watershed of the Buffalo River is only 580 square miles. The St. John's River enters the sea through a great rift in the high plateau on each side of it; and its banks are therefore precipitous, rising 1,000 to 1,200 feet above sea-level, and are thickly clothed with magnificent native bush. There is only just room for the main road to Umtata along the foot of the west bank. The mouth of the river at Porpoise rock is well sheltered from southerly to south-westerly seas by Cape Hermes, which extends 4,600 feet seaward on its western side, and rises to a height of 433 feet above sea-level.

A survey of this river which the Author made in 1897, for the purpose of reporting to the Cape Government on its suitability for a harbour, showed the mouth to be heavily barred by sand, the depth on the crest of the bar, which extended almost straight across the entrance, being only 6 to 7 feet at low water of springs. As the rise of tide at St. John's is only 5 feet, this gave a depth of 11 to 12 feet on the bar at high water of spring-tides—only just enough to admit small coasting craft and tugs. This bar, also, is due entirely to the action of the sea, and not to any deposit from the upland waters. At its eastern end the bar springs from "White's Hill," and at its western end it joins the beach which runs along the west side of Gordon Bay.

One of the conditions present at St. John's, and which in some other cases as well is largely responsible for the very shallow character of the bars, is a projecting headland on the south-western side. The littoral drift of sand takes place, as a rule, in the direction of the littoral current and prevailing seas, which at this part of the coast is from south-west to north-east. Any projection of this kind, therefore, acts to a certain extent like a groyne on the foreshore under its lee, and beyond which it projects. In a less marked degree than at Durban, where at one time the works themselves caused an aggravation of this formation, the same effect is distinctly noticeable under the lee of Cape Hermes; and it is practically certain that if St. John's River entered the sea on a straight line of coast, without any headland on either side of it, the

deep water would be even closer in towards the mouth, and the bar would be more in the form of sandbanks heaped up by the seas within the jaws of the entrance. The projecting Cape Hermes, however, keeps the 30-foot line of soundings at low water nearly ½ mile away from the mouth of the river; whereas it is comparatively close in-shore to the west and east of the bay. This influence, underlying the ordinary bar-formation by the action of the waves, sometimes creates a very formidable obstruction in front of an entrance, which is all attributed to the seas, when it may be due very largely to a faulty disposition of the entrance-works. At Durban, it was first due to the projection of the bluff on the south side of the entrance, and afterwards both to this and to too great a projection of the south in relation to the north entrance-work.

The tidal compartment of St. John's River extends inland for about 15 miles. The lower portion of it, for 2 or 3 miles up, has depths of 10 to 15 feet at low water, and more just within the bar. The tidal volume at springs is about 5,250,000 tons. In the dry season, the river above the tidal compartment is a fine clear stream of considerable width, which brings down no detritus or alluvial matter, unless in flood. For a short distance inland from its mouth the tidal compartment is about 300 yards wide; and farther up it is, in parts, even wider. Owing to its extensive watershed, it is seldom that a year passes without freshets of greater or less magnitude in the St. John's River. One flood is stated to have reached a height of 27 feet above low water of spring-tides 6½ miles above the mouth. At the mouth of the river, it rose 9 feet 6 inches above low water. This flood is said to have swept away the entire bar and westerly beach, forming a depth of 30 feet. Although this flood was no doubt abnormal, such occurrences have to be taken into serious consideration in providing for shipping. For that reason the Author proposed a large tidal basin, extending from the west side of the entrance to the river immediately in front of the site of the township, which would have ample room to spread westwards over the flat ground in this locality, and up the valleys running back into the higher lands to the west.

The main sheltering works proposed under this scheme are an eastern breakwater, and possibly a shorter one at the point of Cape Hermes, where a reef of rocks running out into deep water partially lends itself for a foundation. This, however, from its great exposure nearly square on to the heaviest seas, would be a very expensive work in proportion to its length. After the deepening of the bar by a freshet, it takes a considerable time at St. John's for the bar to

make up again; and it is probable that nearly the whole of the sand which is scoured away by such freshets is deposited farther out in Gordon Bay, and gradually works in again to re-form the bar. The coast-line immediately west of St. John's is very rocky and precipitous, with deep water close in, and with few accumulations of sand along it of any importance; and any littoral current, if it exists at all near the breakers, is so slight that it is of no account as a transporter of sand. There is no doubt, therefore, that the bar at St. John's River exists under conditions which will go far in enabling dredging for its removal to be carried on with economy and success, and that as the area in front of it becomes deepened and denuded of sand, there will be, when the proposed eastern breakwater is carried out, little difficulty in maintaining good navigable depths. In fact, the conditions of this river-mouth are such that the Author felt justified in recommending to the Cape Government the commencement of dredging at the entrance, working in the first instance inwards from the sea to the deeper water within the bar, without waiting for the completion of the eastern breakwater. Where powerful dredging-plant, capable of working among waves 5 to 6 feet in height, can be employed, experience leads the Author to the opinion that much might be done in opening up some of these sand-barred harbours by dredging alone, and without more in the way of works than is necessary to improve the internal regime of the river and concentrate and direct any available scour at the entrance; bearing in mind that the projection of long outer works into the sea is almost invariably attended by a corresponding advance of the shoal-water or bar in front, and that whatever the projecting works, open-sea dredging outside them is almost sure to be a concomitant requirement.

The width of the entrance between the end of the proposed eastern breakwater and the end of the proposed breakwater at Cape Hermes would be 2,200 feet, so that this port would be easily accessible in almost any weather. St. John's is the natural port for Eastern and Western Pondoland, Griqualand East, and the districts of Barkley East, Basutoland, and Maclear. Eastern Pondoland is said to be rich in minerals, and possesses extensive forests at Ekossa, only 20 miles from St. John's. The lands in the neighbourhood of the port are exceedingly rich, and well adapted for the cultivation of all kinds of semi-tropical and other produce. At present, communication between St. John's and the districts mentioned is by road only. The value of the imports to St. John's in 1895 was £6,013, and in 1904 it was £23,185, though hardly anything has been done in the way of works.

Port Shepstone, Natal.—On the coast of Natal there are about twenty-five rivers of various sizes, none of which are navigable. The smaller ones are generally blocked by the extension of the beach across their mouths for the greater part of the year, except when in flood; and all the larger ones have either sandbanks or shallow bars across the outflow of their tidal compartments, or lagoons, into the sea. At one of these rivers, the Umzimkulu, at Port Shepstone, works have been in progress for some years to improve the entrance, and to open the river to the small coasting craft which sometimes make precarious visits to it during periods when the condition of the entrance is favourable. Hitherto, however, they cannot be said to have produced much benefit. So far as its physical features are known to the Author, the river is one which, like the Buffalo River at East London, would be susceptible of great improvement, probably as a fishing-port in the first instance, but capable of development into a harbour of much greater importance when the trade of the districts it serves warrants the necessary expenditure.

To be successful, however, schemes of this nature, at any of the rivers on the South-East African coast, require, in the first instance, the most careful investigation into their physical characteristics, and the fullest recognition of the ultimate expense involved in carrying out the necessary works. Any attempts to carry out works piece-meal and in a tentative fashion, are almost certain to end in disappointment and failure. Even if only small results are desired to begin with, it is always advisable that the works to attain such results should form part of a well-considered and more comprehensive scheme, which aims at the utmost results of which the river in question is found to be economically capable. Not only is this highly necessary from an engineering point of view, but in a new country like South Africa, with possible developments which no one can foresee, it is highly advisable for commercial reasons. When larger views come to be held of the necessities of a growing port, it is always objectionable and expensive to have to sweep away older works, which, conceived under less propitious circumstances, and perhaps without sufficient forethought and experience, stand in the way of the more extensive works for which need has then arisen.

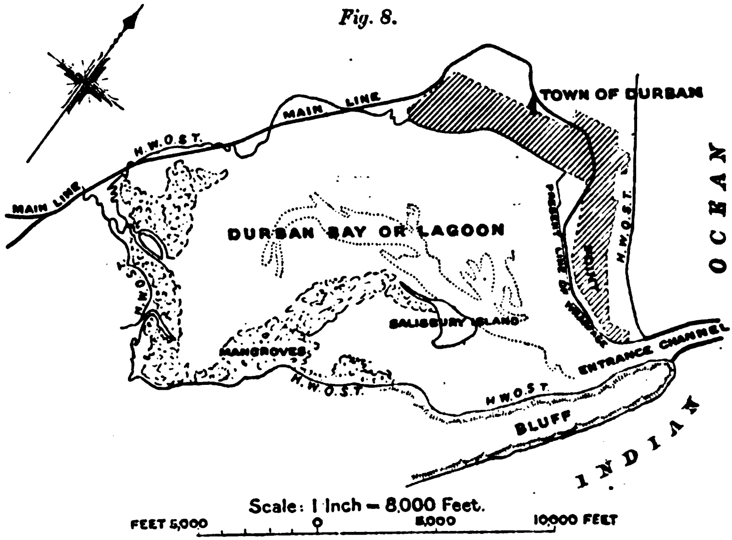
Durban.—The only break of importance on the whole coast-line of Natal is that formed by the inner bay or lagoon of Durban; and this site has therefore been for a long period the harbour of the colony, and the gateway through which a large trade is carried on, not only with Natal, but with the Orange River and Transvaal colonies. Geographically, in fact, Port Natal or Durban

is the natural port for a large portion of both these colonies (*Fig. 1*). The following statistics show the commercial prosperity already achieved by this port:—

Year.	Ships Entering.	Registered Tonnage inwards	Value of Imports.	Value of Exports.	Customs Revenue.
	No.	Tons.	£	£	£
1846			41,958	17,142	3,510
1880	362	198,630	2,336,584	890,874	250,740
1904	912	2,108,658	10,991,302	9,010,389	981,888

During 1904, 395,578 tons of coal were bunkered and exported.

Fig. 8.



DURBAN HARBOUR.

Durban Harbour is a lagoon harbour of a somewhat similar class to those of Malamocco (Venice) and Karachi. The lagoon, which provides a large and valuable backwater, is about 7½ square miles in area. With the exception of a few channels intersecting it, and connecting the mouths of the two small rivers which enter it with the deeper parts near the outflow to the sea, it used to be extremely shallow over nearly its entire area, the bottom being, in fact, a stretch of sand and mud-flats, or banks, which were, and for the greater part are still, covered with about 2 to 3 feet of water at high water of spring-tides (*Fig. 8*). At the south-east side there are some islands which are slightly above high-water level, and are covered by man-

groves and other trees and shrubs similar to those fringing the head of the lagoon. These islands are being gradually and naturally reclaimed by the silting-up of the lagoon by debris and alluvial matter brought into it by the rivers, and by the almost imperceptible elevation of the coast which is going on. The same process accounts for the flats upon which the town of Durban is situated. The Umgeni River, which now enters the sea 3 miles north of Durban, undoubtedly at one time flowed southward within a sandspit between it and the sea, until it met the impenetrable barrier of the bluff rocks and was turned abruptly into the ocean. Its shallow lagoon, long since silted up, must then have occupied the position of the western Vlei along which Durban is now extending. Indeed, it was only in 1856 that, during a high flood, this river, being barred by an accumulation of sand at its mouth, turned southward and flowed over the Vlei, through a portion of the town, and into the lagoon at Durban, or "Durban Bay" as it will hereinafter be termed. It was even proposed at one time to divert this river permanently into the bay, in order that its waters might increase the scour at the entrance of the harbour, a scheme which was fortunately never carried out, as the whole of the detritus brought down would have been deposited in the bay and caused serious silting up.

The rise of the tide at springs is 6 feet; and the tidal volume available for the purposes of tidal scour in assisting to keep the port open, was calculated from the detailed survey made by the Author in 1892, to be about 28,327,972 cubic yards. Since then dredging-operations, where they have removed material above the level of low water, have somewhat increased this. The range of tide at neaps is not more than 3 feet, and occasionally only 9 inches to 1 foot. The tidal volume, therefore, during these tides is very much less than during springs; and the most valuable period of scour is during the first half of the ebb-tide of both springs and neaps, as after that there is little tidal water left to run out, beyond what is contained in the channels. The entrance to the lagoon is between a low-lying sandy spit on the north side, originally, and still largely, consisting of dunes, and a promontory about 200 feet in height on the south side, known as "The Bluff." Its geological structure is described in Mr. Anderson's second report on the geological survey of Natal, as "different from anything else we have on the coast, from the cretaceous rocks of St. John's River to the cretaceous rocks to the north of the Umlatusi lagoon in Zululand. In fact, the rock which forms at the surface the backbone of the bluff, and a portion of the ridge connecting it to the mainland, is certainly younger than anything exposed between the above limits.

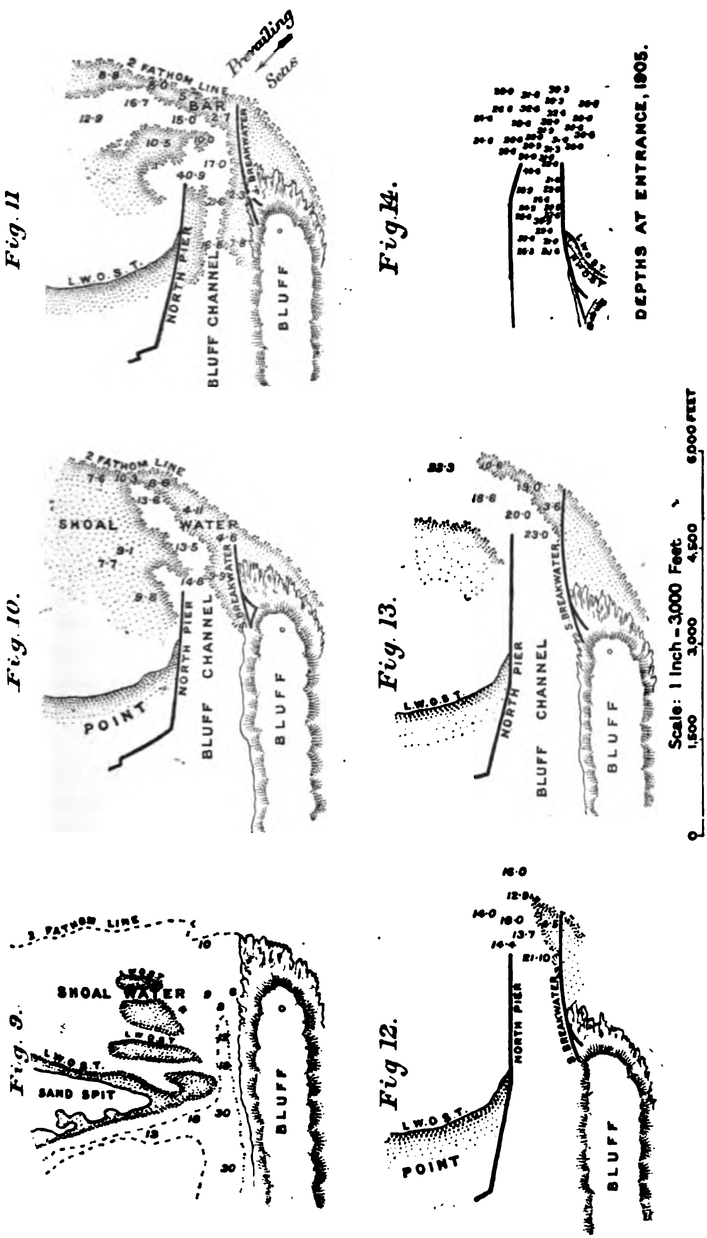
It is a calcareous sandstone showing false bedding, and probably forms some part of the cretaceous series." This cretaceous rock cropped out in several parts of the bluff channel, and had to be removed by the Author.

The deposits forming the Durban flats, including the bay, are the same as those still being deposited in the bay, and consist chiefly of sand, clay, and beds of shelly marl, which occasionally give trouble to the sand-pump dredgers. The estuarine deposits of mud and clay on the surface render these flats agriculturally highly reproductive, a characteristic which is recognized to the full by the many Indian settlers upon them. They are, in fact, very similar in this respect to the estuarine deposits in the neighbourhood of the Tay, the Thames, the Humber, etc., and to the well-known fertile Dutch polders in the Netherlands.

The bar at the entrance to the lagoon, immediately under the lee of the bluff, was one of the most persistent and difficult to deal with known to the Author. Owing to the enormous accumulation of free sand along the coast, to the south of the entrance, for at least 100 miles, and its constant movement, due to both sea and wind, the depths on the bar were always very variable Before the commencement of the present works, the average low-water depth has been generally assumed to be 6 feet, though occasionally it was much less. In February, 1860, there is a record of only 12 inches on the bar, and in July of the same year, 2 feet. The early records of the port are meagre and unreliable; but it is evident that the condition of matters at the entrance was very similar in some respects to what the Author found opposite the mouth of the Umlatusi lagoon, except that it was aggravated by the accumulations of sand which took place under the lee of the projecting end of the bluff, acting as a groyne in relation to the coast-line northward of it. The following notice in the Dessimian Collection of Manuscripts in Cape Town public library, dating from about 1685, seems to bear out the above assumption. "The East India Company would have taken possession of this fertile land (Terra de Natal) years past, but for seeing at the mouth of the Port a reef or sandbank that no galliot without touching could get over without danger; so that a small vessel could not safely go in there."

The form of this bar before any works were undertaken is shown in *Fig. 9*; and the influence of the projection of the bluff is very clearly observable in the accumulation of sand under its lee. The position of the bar has been recorded by the Author by indicating all the shoal water under 2 fathoms in depth.

Before the Author took charge of the Durban Harbour works in 1888, many proposals for rendering the entrance navigable had



ENTRANCE TO DURBAN HARBOUR.

been made by various eminent engineers, including Mr. James Abernethy, Past-President Inst. C.E., and Sir John Coode. Certain works had been carried out under Mr. Abernethy's advice, but they proved unsuccessful, and were, indeed, broken up by the seas; and a northern work of considerable extent, executed under the advice of Captain Vetch, R.E., was abandoned, and afterwards partly removed for the sake of the stone it contained. The main work in progress on the Author's arrival at the port was the south breakwater. A north pier had been commenced under the advice of Mr. J. Milne, and was continued under the late Mr. E. A. R. Innes, Assoc. M. Inst. C.E., but was temporarily abandoned by him before the Author's arrival. Mr. Innes also designed and carried out the earlier portion of the south breakwater, which by 1888 had been carried out 900 feet in advance of the north pier. These works, so far, had increased depth over the bar at low water to 10 feet 7 inches in 1887, and 11 feet 7 inches in 1888; and the bar had assumed the form shown in *Fig. 10*. The works had not been extended nearly far enough to place them in a proper position relatively to the coast-line; and the north pier had been left lagging behind as if it were of no account, leaving the flood- and ebb-tides free to work round its end and form a tortuous northerly channel. The breakwater alone was being pushed on, practically extending the natural projection of the bluff on the south side of the entrance, and tending to close the entrance by causing additional accumulations of sand under its lee, and between it and the beach on the north side of the entrance.

There was no dredging-plant at the port, except an old bucket-dredger and a small stationary sand-pump dredger for reclamation purposes inside the bay. Before leaving England for Natal in 1888, however, the Author visited Holland; and after inspecting the work of dredging on the River Maas, he ordered, on behalf of the Government, a sand-pump dredger, of what were then considered large dimensions, from Messrs. Simons and Co. of Renfrew, as well as a powerful bucket-dredger for the harder material which had to be dealt with in the bluff channel and elsewhere. The sand-pump dredger had a hopper-capacity of 500 to 600 tons, and two suction-pipes, one on each side, 15 inches in diameter. She afterwards did good work, both on the bar and inside the harbour, for which latter she was more suitable.

After mature consideration of all the facts ascertained during a protracted period of investigation, the Author recommended that the north pier should be extended until it was abreast of the breakwater, and that dredging should be resorted to on the bar to supple-

ment the scour then induced by the works; pointing out the great burden on the port which continuous dredging would create, and the consequent necessity for minimizing it by utilizing to the utmost the tidal scour available from the bay. He also made provision for a further extension of both works on a slight northerly curve for 600 feet, should this be found necessary after the extension of the north pier; but the authorities strongly opposed any further extension of this work. As the breakwater advanced farther ahead of the north pier, thus increasing the projection on the south side of the entrance, the bar, or rather the area of shoal water which formed under its lee and across the entrance, progressed with it. When the breakwater went ahead rapidly, the ridge of the bar occasionally came just within its end, being beaten inwards by the heavy seas; but in a very short time it again headed the work before any further extension of the northerly pier was begun, and also during and after its construction out to the point it reached in the period during which the Author had charge of the works. The form the bar usually took is shown in *Fig. 11*, which is taken from a survey made just before the commencement of the north pier extension, and when that work was 1,300 feet behind the breakwater. The dotted areas show the sand accumulations, or shoal water less than 12 feet in depth. Under these conditions, the scour from the ebb-tide was dissipated to the north round the head of the shorter work, the waters finding their level in the ocean outside by the shortest route. It was therefore necessary, for the navigation, to train the tides as far as possible on the line of the axis of the bluff channel. This was also the only practicable line on which dredging could be carried out; for dredging in a more northerly direction would have brought the craft broadside on to the seas.

An endeavour was being made, before the Author took charge of the works, to cut off the sand-supply by the extension of the south breakwater only; but the Author pointed out that this was absolutely impracticable. The only result the work had, by itself, was to cause accumulations of sand under its lee and across the entrance. A sufficient extension of it would have caused the entrance to become blocked altogether, by lengthening the base on which the accumulations rested. As, however, it was a necessary work in conjunction with the north pier, and, from its greater exposure to the prevailing seas, had to be made much stronger, its progress was slower than that of the north pier, so that it was continued while the latter work was being brought up to overtake it. Before this could be done, however, its increasing overlap diminished the average depth over the bar to 10 feet 1 inch. The effect of the extension of

the north pier was not only to train the ebb-tide, but also to narrow the width of the entrance from 900 feet to 800 feet, and so increase the scour from the bay. The scour, however, was quite unable to maintain the necessary navigable depth in so wide a sectional area as that of the bluff channel; and in 1890 the Author pointed out that the width might have to be still further reduced, which has since been done. As the immediate result of the extension of the north pier to a point 700 feet short of that which the breakwater had reached, the depth of 10 feet 1 inch in 1890 was increased to 13 feet 8 inches in 1892. In March, 1893, the depth on the bar averaged about 13 feet 6 inches, though no dredging had been done on it since October, 1891. This was a remarkably good increase of depth in so short a time; but it was followed by a gradual reduction to 12 feet 1 inch in 1895, even although during these years every effort was made, with the available dredging-plant, to maintain and increase the depth.

It was not until 1894 that the Author was able to order a powerful dredger for open-sea work on the bar, in accordance with a specification which he had prepared several years before, and for which he repeatedly made application. For this dredger, the "Octopus," he partly took as a model the "Brancker," the well-known pioneer of this powerful class of craft on the Mersey bar. Her hopper-capacity was fixed at 1,200 tons, as it was then considered by the port-authorities that this would be as large a craft as could be handled with safety on the bar, and exposed to heavy seas. Subsequent experience has shown the practicability and advantage of working considerably larger craft in this situation. The main suction-pipe of the "Octopus" was 42 inches in diameter, and placed in a central well, and it was of sufficient length to enable the vessel to dredge considerably below the depth required for navigation when at an angle of only 45°. She had separate pumping-engines, in addition to her propelling engines, and two large centrifugal pumps with 24-inch suction- and discharge-pipes working out of the main suction-pipe. The plan of dredging well below the required navigable depth outside the entrance, and thus making allowance for any shoaling during rough weather, the Author saw in use in Holland in 1888, where it was regularly practised by the Dutch, who at that time were considerably ahead of English engineers in sand-pump dredging. The contract dredging-capacity of the "Octopus" was 3,000 tons of sand per hour; but her record time in filling her hopper with 1,200 tons of sand was about 13 minutes, or nearly 100 tons of sand per minute. This vessel, which was the first of the present fleet of these powerful dredgers at Durban, did not arrive until 1895; and the

Author pointed out to the Legislature that with her advent would commence "greater experiments of outer-sea dredging than had probably been tried in any other part of the world." He thinks it may safely be said that this prediction has been verified.

Reverting to the outer works, in 1892, in spite of his most urgent appeals, the Author found it impossible to obtain sanction for the further extension of the north pier. He therefore decided to stop any further projection of the breakwater until the north pier was brought up abreast of it; and it has not been extended since. These works, therefore, remained as they were for some years, with the end of the south breakwater about 700 feet ahead of the north pier.

The changes on the bar during this time are shown in *Figs. 12* and *13*. The original overlap of the bluff beyond the sand-spit on the north side of the entrance, now known as "The Point," and before any works were begun, was the governing factor as regarded the area of the shoaling which then took place to the north of it, for it acted as a huge groyne in relation to the coast-line to the north, and induced shoaling under its lee, as shown in *Fig. 9*. After the extension of the north pier to within 700 feet of the breakwater end, the same formation, which for a time was broken through, reappeared in the form shown in *Figs. 12* and *13*.

It was then quite apparent that the reduction of depths between 1893 and 1895 was due entirely to the overlap of the work on the south or weather side, the side from which the heaviest seas, the littoral current, and the sand-travel came. To dredge under such conditions was to preserve a state of affairs which was equivalent to putting sand in front of the entrance with one hand in order that it might be taken away with the other. While the tide ran in and out round the head of the north pier, it only tended to form a northern channel there; and the dredgers were employed in forming one on the axis of the bluff channel. In fact, Nature was being pitted against the artificial power of dredging, and if she did not win, the only result would be to greatly increase the annual cost of dredging, instead of reducing it to a minimum by bringing forward the north pier abreast of the breakwater, and inducing the two powers to work together. These views were constantly insisted upon by the Author, but without avail; and in 1895 his professional connection with these works ceased.

Some time before this, the Author suggested to the Government that independent opinion on the subject should be sought; but it was only subsequently arranged that Sir Charles Hartley, K.C.M.G., M. Inst. C.E., should visit Durban in 1896. Sir John Wolfe Barry was also retained to act with Sir Charles Hartley in advising the

Government; and in 1897 they advised, in an able report,[1] the immediate extension of the north pier until its end was abreast of that of the south breakwater, and a still further narrowing of the entrance to 600 feet, in order to increase the scour from the bay. In addition, they advised persistent dredging on the bar in the open sea. The north pier was then extended until its end was abreast of that of the breakwater, and at a slight angle, so as to narrow the entrance; and dredging with the "Octopus" and her sister craft was carried on in addition. The scour, induced and trained by the extension of the north pier, was brought to bear in assisting and maintaining the work of the dredgers. The result has been that the average depth at low water on the bar in 1902 was 18 feet 5¼ inches; in 1903 it was 21 feet 3½ inches; in 1904 it was 25 feet 9 inches; in the earlier part of 1905, 27 feet 6 inches; and in October 1905, 30 feet (*Fig. 14*). Since June, 1904, the largest mail-steamers have entered and left the harbour in perfect safety.

The following figures show the quantities dredged outside the works, and for a distance of about 700 feet inwards from their ends, that is, on, and in the neighbourhood of, the bar:—

Year.	Dredging. Tons.	Average Depth at Low Water Feet.	Inches.
1897	567,700	17	3
1898	775,800	18	7
1899	353,700	19	7½
1900	377,250	19	8⅓
1901	684,550	19	1½
1902	711,400	18	5
1903	1,123,650	21	3½
1904	1,021,000	25	9

The north pier extension was completed at the end of 1900.

From the above figures it will be seen that the increase in the depth over the bar is by no means in exact proportion to the amount of dredging. In 1898, though 775,800 tons were dredged, the average depth over the bar was 18 feet 7 inches. On the other hand, though little more than half that amount of dredging was done in each of the years 1899 and 1900, the average depth increased to 19 feet 7½ inches, and 19 feet 8⅓ inches in these years respectively. During these years, however, the north pier was being extended, and was made fully effective at the end of 1900. The depths then fluctuated between 19 feet 1½ inch and 18 feet 5 inches in 1902, a decrease, though the dredging was nearly doubled.

[1] "Port Natal: Report on the Existing Works, with Proposals for Further Improvements of the Harbour." London, 1897. (Copy in the Institution Library.)

The dredging was then increased to 1,123,650 tons in 1903, an increase of 412,250 tons; and the depth increased to 21 feet 3½ inches. But in the following year, 1904, the dredging was less by 102,650 tons; while the depth increased to 25 feet 9 inches. Such are the uncertainties of weather, and the consequent movement and deposition of sand, that it is unsatisfactory and misleading to draw any conclusions from comparison of the results of one year with the following. In such cases considerably longer periods are necessary; and thus it is found that in 1904 the amount dredged on, and in the neighbourhood of, the bar, was greater by about 31½ per cent. than that dredged in 1898, before the extension of the north pier was far enough advanced to be effective; but the increase of depth in 1904, after the completion of the north pier in 1900, was about 38½ per cent., namely, from 18 feet 7 inches to 25 feet 9 inches at low water.

This splendid result is undoubtedly due to the proper training and increase of the tidal scour, coupled with the dredging-operations. In fact, there can be no doubt that, before the extension of the north pier, the natural tidal scour and the dredging were largely opposed to each other; and the liability of the bar to the sudden shoalings which frequently took place during very short spells of bad weather—sometimes lasting not more than about 24 to 48 hours—reducing the depth much below the loaded draught of the dredgers, made it impossible to work these effectively, or with any hope that their work would be maintained.

The dredging-fleet at Durban now consists of twelve dredgers, several of them large hopper-dredgers provided with powerful sand-pumps of the "Octopus" class, with central well and separate pumping engines, and with a combined dredging-power of not less than 7,000,000 tons of sand per annum; but when it is borne in mind that not only have constant operations to be carried on on the bar at the entrance, but that a great work of deepening in the shallow bay, and of land-reclamation round its margins, has also to be carried out, the plant is not excessive, though it is very large in proportion to the revenue of the port. The cost of dredging in free sand varies according to the site between a little more than 1*d.* per ton and 3*d.* per ton, the cheaper work being done by the dredgers of larger hopper-capacity.

With respect to the outer works, and the minimizing of dredging at the entrance, in the Author's opinion everything has not yet been done that is possible in this direction. It is of great importance in all cases of this kind that the termination of the works should be placed in proper relation to the coast-line, so as to be, if possible, beyond

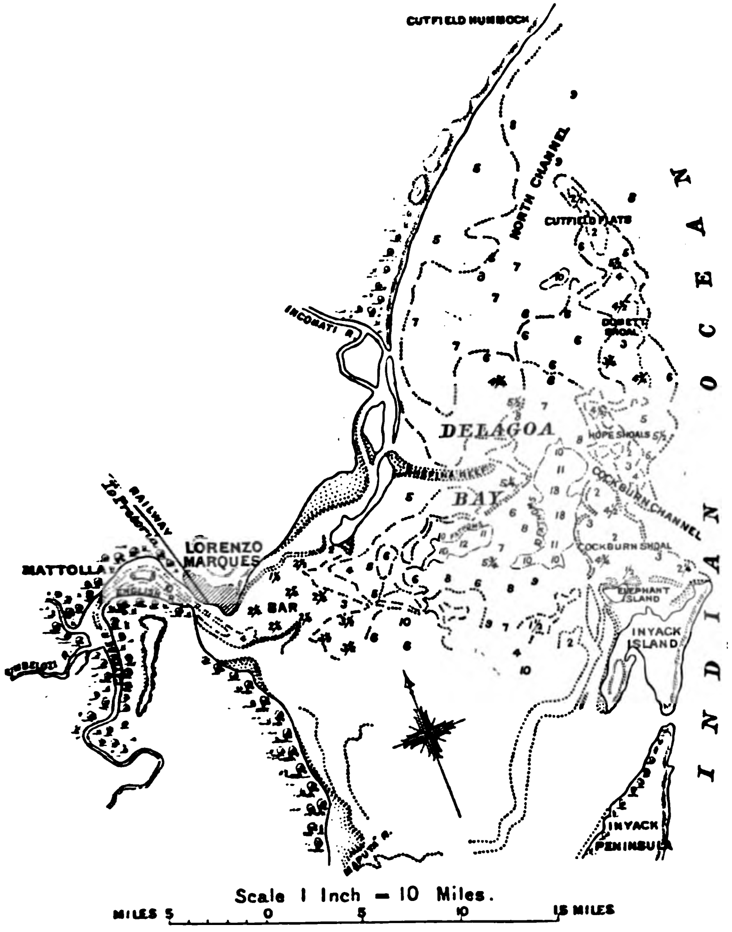
the influence of any peculiarity in its contour which might cause deposition about the entrance. There is an interesting indication among the earlier surveys of the Durban bar that this has not been quite reached, and that, if it were, the result might be undiminished depth, and at the same time considerable decrease in the annual cost of dredging the bar. The bluff does not taper at its seaward end to a fine point (*Fig. 13*); and in consequence of this, and of the direction of the seas and the littoral current up the coast, a sand-spit, with 12 feet in depth at low water of springs, formed in 1885, and again in 1887, springing from the broad end of the bluff as a base, and between the seas and littoral current on the south side, and the outflowing and inflowing tide on the north side. Had the end of the bluff been wider, thus forming a wider base for the spit, the latter would have been longer. It is clearly visible on several of the surveys, and is a certain indication that the south breakwater, the end of which is short of the length of that spit, is still within the influence of shoal water so caused. This natural indication, so clearly and repeatedly shown by the surveys, was taken by the Author as a guide in determining the length to which it might ultimately be advisable to extend the works, in case, after the north pier had been brought up abreast of the breakwater, it were found necessary to go farther. As there is, however, the interest to be reckoned on the cost of the additional works, it is difficult to determine whether any saving in dredging would more than counterbalance this. The point is nevertheless of interest, as an instance of the indications which Nature sometimes gives the engineer as to the proper course to follow.

In the treatment of bars on sandy coasts, the great development of the sand-pump dredger has come to the engineer's assistance, and has made it possible to deal with cases which it would have been hopeless to attempt before; but it must not be imagined on that account that it has made these problems any easier to solve. Heavy dredging when, unfortunately, it is necessary to supplement the natural forces, is very costly, and has to go on for all time: it thus becomes a millstone around the neck of any engineering and commercial enterprise depending on it. It is therefore the first duty of the engineer to see that, in the disposition of the works, he utilizes to the utmost degree, and in the most effective and economical manner, any natural forces available, so as to minimize the amount of dredging necessary: and it is here that the problem is as great as ever.

Delagoa Bay.—Delagoa Bay, though not a British port, ranks not only as one of the principal ports of South Africa, but also as one of the great natural harbours of the world, more, indeed, by reason

of its possibilities than owing to its present state of development. Although a bay in one sense, it appears from *Fig. 15* to be in a state of transition between a bay and a lagoon on a gigantic scale. It receives four main rivers, namely, the Tembe and Umbelosi,

Fig. 15.



Delagoa Bay.

flowing with the smaller Mattolla River into the inner lagoon, called sometimes the "English River," the Maputa flowing into the so-called bay at the back of Inyack Peninsula, and the Incomati flowing in at Shefina reef.

The distance across the mouth of the bay proper, from the north end of Inyack Island to the mainland at Cutfield Hummock, is about 35 miles; and the width across from this line westwards to Reuben Point at Lorenzo Marques is about 23 miles.

The deep-water entrance to the bay is between the points of Shefina reef and the Cockburn shoal, which extends about 5 miles northwards from Inyack, with depths of only ½ fathom to 3 fathoms on it. This entrance is 60 to 72 feet in depth, and about 3 miles wide; and it has a bar at its outlet, which, though it has varying depths over it of 3 to 7 fathoms, is, nevertheless, a bar in relation to the much greater depths immediately within it. Owing to the uncertainty and variability of these depths, it also constitutes a very real bar to the larger class of vessels entering the port. There are, in fact, only two highways for large vessels into the bay, one from the north within the shoal referred to, and the other, and more generally used one, by the Cockburn channel round the point of Inyack.

The submerged spit, formed by the "Cockburn," "Hope," and "Domett" shoals, with the "Cutfield flats" at their northern point, resembles on a very large scale the form of the sandspits which exist between all the smaller lagoons previously referred to and the sea. Again, on examining the northerly deflection of the deep-water entrance between the Shefina reef and Cockburn shoal, the curved bar-formation encircling the entrance is very apparent.

The Author has heard expression frequently given to the mistaken idea that Delagoa Bay, or its harbour at Lorenzo Marques, is accessible to the largest vessels at all states of the tide. The plan shows, on the contrary, that outside the entrance to the English River, or inner lagoon, there is a very extensive bar. This bar, which has depths over it of only 2¼ to 3 fathoms, with a governing depth of 2¼ fathoms, is slightly over 4 miles wide. It is clearly not of the usual bar-formation, previously referred to as being due to the action of the waves on the sand. There are, in fact, never any heavy seas at this part of the bay, as they are broken up by the outside shoals when they come from the east; and when coming from south-east, the peninsula and island of Inyack stop them. This bar is caused by the deposition of matter brought down in suspension by the rivers entering the inner lagoon. As soon as the river and tidal waters emerge from the narrow outlet opposite Lorenzo Marques into the rapidly widening area of the outer bay, the current slackens, and deposition occurs. There is a rise of tide, however, at Lorenzo Marques of 12 to 13 feet at springs, so

that at high water vessels of considerable draught can cross the bar to the deeper water inside.

To dredge a channel 18 feet in depth at low water of springs through this bar would involve about 4⅓ miles of dredging; a channel 24 feet deep would involve 5½ miles of dredging; and a channel 30 feet deep would necessitate about 8 miles. No doubt these extensive operations will be undertaken some day. The deposit forming this bar must have occupied an immense period in accumulating; and in such a situation the effect of dredging may be regarded as practically permanent, when once the side slopes have taken their natural angle of repose. At all events it is probable that once the channel is dredged, its maintenance will be no more serious than are similar operations carried on in the Mersey estuary or at New York. The ultimate fate of the Cockburn channel in such an exposed position is not easy to predict: it is probable that dredging difficulties may have to be faced here—possibly in the far future—which may tax the best energies of the engineers of that day; but no doubt they will be overcome.

The possibilities as regards the development of the harbour are limitless, and depend upon the development of the immense tract of country behind it, of which it is the natural port. It is to be hoped that what is done towards that end will be begun upon a well-considered general plan, far in advance of the times, and not built up in a haphazard way.

The Paper is illustrated by twenty tracings, from some of which the Figures in the text have been prepared.

[DISCUSSION.

Discussion.

The President. The PRESIDENT moved a vote of thanks to the Author for his Paper.

Mr. Matthews. Mr. WM. MATTHEWS, Vice-President, having been long associated with some of the harbours referred to in the Paper, desired to make a few remarks on those of Cape Town, Port Elizabeth and East London. The works at Cape Town, designed by Sir John Coode in the year 1860, consisted of a small dock or basin, without gates, about 8½ acres in extent, with an outside basin of about 4½ acres, and a breakwater 3,000 feet in length. Although engineers of the present day would look upon that as a very modest undertaking, the proposal to carry it out had been considerably criticized on account of the extent of the works, which were considered altogether beyond the requirements of that time. Sir John Coode had lived not only to see the execution of those works, which had answered their purpose, but also, in consequence of the great development of steamer traffic, to propose the outer Victoria Basin of 64 acres; and he had been engaged in the construction of that work at the time of his death. The harbour at Cape Town was not subject to reduction of depth by deposition of sand or silt. In that respect it differed entirely from the other harbours farther up the coast. At Port Elizabeth the jetties designed by the late Sir John Coode were of open iron piling, and when Mr. Matthews saw them about 11 years ago, although they had then been in existence for 15 years or more, the ironwork was almost as good as when it was put down. That satisfactory result might, he thought, be attributed to the marine growths and shell-fish adhering to the ironwork, which had formed an efficient protection to the iron. The Author spoke of the jetties not being available for the berthage of vessels; but they were not intended for that purpose. At Port Elizabeth, as would be seen from *Fig. 3*, there was a series of jetties extending from the shore, alongside which surf-boats and barges were berthed. The vessels themselves lay out in the roadstead; the cargo was discharged into the barges, brought alongside the jetties, lifted by hydraulic cranes, put into wagons, and then taken up country or put into the stores. Similarly, wool and other produce for home was brought down and shipped from the jetties. It was not intended that the jetties should do more than furnish accommodation for barges and small coasting craft. At Port Elizabeth the

Mr. Matthews.

sand-travel was very active. Before the erection of the jetties a local engineer built out from the shore a solid structure, almost at a right angle. In consequence of this the shore and the work itself became blocked by such an extensive accumulation of sand that Sir John Coode was called in to devise some means of getting rid of the sand, and he advised that the most economical and effective plan was to remove the structure, which was done. The accumulation which occurred, however, had furnished an indication of the rate at which sand was deposited there: that was really an important point, which had given a clue to the subsequent treatment of the harbour. The accumulation of sand was due partly to the oblique impingement of the waves on the coast and partly to sand blowing across the promontory, of which Cape Recife formed the south-eastern extremity, and travelling up the coast. When he was there 11 years ago the travel across the neck had been very considerably reduced, in fact it had been almost entirely overcome by distributing town refuse over the bare sands and planting rough seeds on it. A considerable vegetable growth had resulted on what were previously bare sands, so that the sand was stopped in its passage across the point, and was therefore prevented from travelling along the coast. The data obtained from the solid work to which he had referred showed that the rate of accumulation was about 600,000 cubic yards of sand per annum. The proposed new harbour, which was 740 acres in area, was based on the principle of leaving an opening at the shore end of the east breakwater through which the travelling sand could pass, to be dealt with by means of pump-dredgers inside, under the lee of the breakwater. He felt confident that modern dredging-appliances could easily deal with the sand which would travel into the harbour, and in that way the sheltered harbour which Port Elizabeth had been looking forward to for so many years would be secured. With regard to East London (*Figs. 6* and *7*) his old friend Mr. Charles Neate, M. Inst. C.E., went out there in 1869, for Sir John Coode, and obtained information on which Sir John prepared his design for the work. When the design was prepared it was possible to wade across the river; but when Mr. Matthews was there about 11 years ago vessels of 5,000 tons were going in and out of the port regularly. That result had been brought about by two causes. In the first place there was the concentration of the backwater, which, though not very extensive, was subject periodically to tremendous freshets which cleared everything out of the river for the time being. The sand then collected again; and for some time after the works had been projected and were in

Mr. Matthews. hand, accumulation of sand occurred. In consequence of the exposure of the coast it was not practicable to use bucket-dredgers, and it was only by the use of pump-dredgers that that harbour and Durban Harbour had been brought to their present condition. Of course, without the training-works the pump-dredgers would not have been so effective. The introduction of the pump-dredger was due to the Dutch. They were brought to England by Sir John Coode, who, as a Commissioner of the Suez Canal, went to Holland in connection with Suez Canal work, and there saw pump-dredgers at work. It struck him that they were exactly what he had been in search of for a long time to aid him in the creation of the deep entrance at East London. There, as the Author pointed out, the dredgers were continually at work, and Mr. Matthews believed that neither Durban, which had a much more effective backwater than East London, nor East London, could be kept open without the use of pump-dredgers. Both had been looked upon as being about the two worst bar-harbours in the world, and he thought the manner in which the entrances had been kept open, and in which the navigation of large vessels had been rendered possible, was a matter for congratulation.

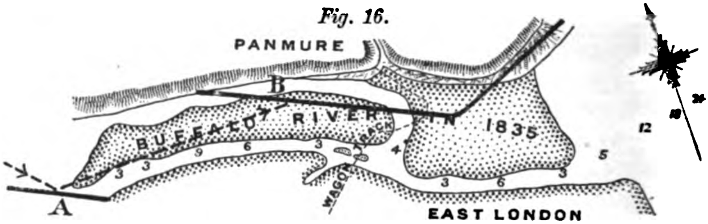
Mr. Gonsalves. Mr. George Gonsalves remarked that the fact that the Author had dealt solely with the harbours on the east coast of South Africa might lead to the supposition that no harbours existed on the west coast. He desired to draw attention to a fine natural harbour in Portuguese South-West Africa, namely, Lobito Bay, situated in about 12° south latitude. At present that harbour was little known, owing to the small quantity of shipping which made use of it; in fact, until within the last 12 months very few ships had called there. The construction of the Benguella Railway, starting from Lobito, was now, however, well in hand, and as that railway would eventually run from the coast about 900 miles into the interior of Africa, tapping the rich copper districts of Katanga and also shortening the route to the Rand by at least 6 days, he felt sure that in a very few years the harbour of Lobito Bay would be as well known as that of Delagoa Bay or Durban. The harbour at Lobito was undoubtedly the best on the south-west coast of Africa. It was formed by a tongue of land 3¾ miles long, running east and west and parallel to the mainland, which acted as a breakwater, and so enclosed a harbour 3 miles wide, with an entrance ¾ mile across. The bottom was sandy, and afforded good anchorage. On the north side of the bay the beach was very steep, there being in most places 10 fathoms of water within 300 feet of low-water mark, and as much as 30 feet within a few yards of the land itself, so that it was possible for

vessels to practically come alongside the tongue of land and discharge there. Captain Neilson, of the Union-Castle S.S. "Gascon," after taking his steamer into the harbour with material for the railway in July, 1904, reported very favourably on it to his company. There was no bar at the entrance, and the range of the tide was only about 4 feet. A timber pier 600 feet long had been built parallel to the shore, alongside which steamers drawing more than 30 feet of water could lie and discharge at any state of the tide. Mr. Gonsalves.

Mr. WOODFORD PILKINGTON considered that the idea of using the Zwartkops River was impracticable, because it faced south-east; moreover, the vested interests at Port Elizabeth would prevent such a scheme from being carried out. It was not the case, as the Author implied, that no really serious work was done on the Buffalo River before 1870, because in 1856 Mr. Pilkington constructed some training-banks there; and at that time 60 feet of water existed in the lagoon opposite Panmure. He also made, in 1866, the only trigonometrical survey of the river. The inshore quay-wall in *Fig. 7*, as far as the wave-trap inside the breakwater, was just what had been left so far finished when the work was taken over by the late Sir John Coode. This was proved by the two soundings, 11 feet 3 inches and 9 feet 9 inches, on rock surface close in. It had not been Mr. Pilkington's intention to leave a wave-trap, but quite the reverse, namely, to continue the line of the quay-wall to a junction with the breakwater, thus leaving the wave force at this point to help the incoming tide, so as to increase, as far as possible, the quantity of water coming into the estuary, and thus enhance the scour during the ebb-tide. The east pier was wrongly placed, if wanted there at all. The engineers had reached the maximum depth of water (18 feet) attainable in the centre with a rock bottom, by hugging the western bank. As the Author stated that the difficulty in the navigation of the entrance due to the east pier and the construction of the entrance some little distance within it would be remedied in course of time, it would be interesting to know what were the proposals for its improvement which were said to be under consideration. On the River St. Lawrence dredgers having the buckets fitted with tines cut into laminated schist 20 feet below the surface at the rate of 240 tons per day; but this could nowhere be done in igneous formation. If the authorities were content with the entrance of coasting steamers the east pier might remain; but if not, and if a possible depth of 30 feet to 40 feet at low water were desired, the pier should be simply cleared away. But first he considered that the cushions shown in *Fig. 16*, as originally designed by him in 1856–7, should be constructed to take advantage of the principle of "incidence and Mr. Pilkington.

Mr. Pilkington. reflection." He would place a cushion at A to cause deflection of the ebb or freshet current direct to the Panmure side, where an esplanade on reclaimed ground would form a second cushion, B; and he would strictly avoid all such training-walls as the east pier. The Buffalo River had probably a winding length of 60 miles or 70 miles,

Fig. 16.



with a watershed twenty times that of the Kowie, with which it bore no comparison. It had once, towards the middle of the nineteenth century, been flushed down to the rocky bottom; whereas the estuary and swamp of the Kowie had probably not been so scoured within the memory of man.

Mr. Tripp. Mr. W. B. Tripp, having been connected with the port of East London many years ago, was personally familiar with the action of freshets there before any works were built. Since then the magnificent works described in the Paper had been constructed, and had proved highly successful. He believed that since 1876 freshets had practically ceased to occur, though apparently one happened in 1905, as the result of a very heavy fall of rain (about 11½ inches) on the 9th, 10th, and 11th October. It would be interesting to know what the effect of that freshet had been on the present harbour at East London. Even without the aid of freshets, the dredgers maintained a depth of 18 to 20 feet of water.

Sir Guilford Molesworth. Sir Guilford L. Molesworth, K.C.I.E., Past-President, mentioned that 16 or 17 years ago he was consulted on a scheme for the improvement of Port Elizabeth, the suggestion being that an open piled jetty should be constructed, approximately in the position of the east breakwater shown in *Fig. 3*. It was proposed to add to this jetty open breakwater screens, with the idea of quelling the waves, and producing still water within the area protected. He made many elaborate experiments with models of open screens of different forms, in order to ascertain the effect; and although it was of course not always safe to rely upon the results of experiments with models, the results in this case were such as to convince him that the scheme would be a failure: he could not recommend its adoption, and therefore it was abandoned.

Mr. Elliott-Cooper.

Mr. R. Elliott-Cooper remarked that 28 years ago Port Alfred was believed to have a promising future. At the time of his first visit to South Africa, in 1878, the harbour had just been commenced. Many years previously, about 1856, an attempt had been made to convert the Kowie River into a harbour, so as to render the entrance fairly practicable, at any rate for small ships. In 1878 Sir John Coode recommenced the work, and it had at that time apparently every prospect of success. The people of Grahamstown and of Port Alfred had such faith in the project that they obtained an Act of Parliament for the construction of a railway between Port Alfred and Grahamstown, the latter place being at that time the distributing centre for that part of South Africa, from which the interior was reached by means of bullock-wagons. The Act of Parliament was carried into effect by a company formed in London, to which he became the engineer. When he went out in 1878, to be present at the cutting of the first sod, he thought the place was going to be one of the ports of South Africa. But here, as in so many other cases in Cape Colony, political influences soon began to make themselves felt. Port Elizabeth looked with considerable jealousy upon the possibility of Port Alfred becoming a competitor; and when it was borne in mind that Port Alfred was only 40 miles from Grahamstown, whereas Port Elizabeth was 102 miles, it would readily be understood that the difference in railway-rates appeared as if it might have some effect upon Port Elizabeth. The effect of the influence which was brought to bear upon the Government was that the railway-administration was induced to lower the rates between Port Elizabeth and Grahamstown to such a degree that all the geographical advantages of Port Alfred in respect of access to Grahamstown were practically lost. As mentioned in the Paper, the trade began to fall of, and within about 4 or 5 years the harbour was entirely abandoned. He thought that was a great pity, because all the success which had followed upon the works at East London would, he believed, although perhaps to a less degree, have attended the works at Port Alfred, where there was a river navigable for about 14 miles, and about 250 feet to 400 feet wide. The land on each side of the river was comparatively low, and easily adaptable for the making of inland docks. The railway, of course, continued working, but it was now used almost entirely for taking people from the upper part of the country to Port Alfred as a health and seaside resort, and for local traffic. That was one of not a few instances in South Africa where political influences, and the jealousy which one district had of another, had retarded the progress which ought to have taken place. The illustrations of the Paper showed many sites of possible

Mr. Elliott-Cooper. harbours, and some members might fancy they would live to see works carried out there; but he had not the faintest hope that such would be the case. For instance, extension of the docks at Cape Town had been proposed by Sir John Coode and his firm ever since Mr. Elliott-Cooper had known South Africa. When he was in that country 5 years ago, at the time when Mr. J. C. Coode, M. Inst. C.E., was also there, it really looked as if some definite steps would be taken to carry out that great work; and he believed that if that had been done then it would have gone a long way towards maintaining the supremacy of Cape Town as the controlling port for the inward traffic of South Africa. But nothing had been done, and he was sorry to say that, in view of the present state of trade in South Africa, there did not appear to be any serious necessity for large extensions in Cape Town. The same remarks applied to Algoa Bay. In one form or another the piers shown in *Fig. 3* had been proposed certainly for the last 25 years, but they had never got beyond being proposals. Whenever an agitation arose, the Government obtained a report of what could be done; by the time that report had been circulated, a couple of years or so had probably elapsed, and the Government then dropped the matter for a few more years: and very often nothing further was heard of the scheme. That, he thought, was a great misfortune, because it destroyed the faith of the traders as to the intentions of the Government in regard to any great future developments. If a definite scheme, similar to those which had been carried out so successfully at East London and at Durban, were put in hand, instead of a large number of schemes being prepared, tenders obtained, and nothing done, it would save much money and be much better for the welfare of South Africa. It was impossible to exaggerate the advantages which had accrued from the two works which had been successfully completed at East London and Durban. When he first went out passengers had to land at East London in surf-boats—a miserable performance; but now, as Mr. Matthews had explained, the largest steamers were able to go into the port, and the same remark applied to Durban. With reference to the proposed dock at Zwartkops, he did not quite know how vessels would make the entrance in anything like bad weather. He had been in the bay when a storm was blowing, and it was then impossible to approach the shore, the coast being very dangerous.

Mr. Hunter. Mr. Walter Hunter, having seen the works at Table Bay and also those at Durban, thought it must be a source of great satisfaction to those towns, and also to the engineers who had carried out the works, that they had been so successful. That was parti-

cularly the case with regard to the magnificent sheet of water at Durban. When he first went there in 1903, vessels had to stop outside the bar; but when he visited South Africa again in 1904 and 1905, through the skill of the engineers in constructing the works, and owing to the dredging which had taken place, the largest steamers, such as the "Saxon" and the "Walmer Castle," both ships of more than 12,000 tons, were able to go safely into the harbour and alongside the quay. Mr. Hunter.

Mr. C. H. Colson desired to ask what considerations had led to the fixing of the length of the breakwater at Durban. He understood that dredgers had to be continually employed in order to remove the sand which accumulated across the entrance, and which swept up sideways across the breakwater. He presumed the breakwater had been constructed to its present extent in order to lessen the accumulation in front of the entrance; and it would appear that if it were prolonged the amount of dredging might be still further reduced. The question might be one of cost, but he thought it would be of interest if those who were responsible gave a little information with regard to the general lines of the design. Mr. Colson.

Mr. James Meldrum remarked that it would be extremely instructive if Mr. Methven would give diagrams of the forces which were acting, particularly one in reference to the harbour of Durban. Engineers desired to know not only the direction of the river-current (if any), but also the direction of the littoral current, of the prevailing waves, and of the prevailing winds. Without that information no engineer was in a position to decide whether the breakwaters had been originally designed in the correct direction. He laid great stress on that point, because he had had the pleasure of meeting the Author on the spot about 13 years ago, and they had agreed that it might have been possible to overcome the difficulty by adopting a single curved breakwater, arranged in such a way that the littoral current would assist in removing the deposit in front of the harbour, and not, as at present, cause the formation of one. Mr. Meldrum.

The Author, in reply, stated that he was well aware that, as Mr. Matthews had pointed out, the existing jetties at Port Elizabeth were not intended for the accommodation of large vessels, but only for lighters and small coasting craft. The system of discharging vessels in the open roadstead into lighters, which in turn discharged at these jetties, involved a great deal of handling and consequent expense, before the goods could be finally sorted and dispatched to their destinations; and the construction, either at the Zwartkops River or elsewhere, of a sheltered harbour, where the trade could be carried on in safety alongside wharves in the usual way, was The Author.

The Author. imperative if Port Elizabeth was to compete successfully with such ports as East London, Durban and Delagoa Bay. The proposed new harbour in front of Port Elizabeth (*Fig. 3*) was, however, of so costly a nature, all quayage and working- or storage-area having to be reclaimed from the sea and therefore being necessarily limited in extent, that there was a great deal to be said in favour of the Zwartkops scheme, notwithstanding vested interests in the neighbourhood of the present jetties at Port Elizabeth. It was clear that the proposed harbour in front of the town would be practically useless unless both arms were constructed, and its completion, ready for traffic, would take much longer than the work necessary to render the Zwartkops River available for at least a large portion of the trade of the port; while the latter scheme would cost only about half as much as the former. The value of the almost unlimited area of land in immediate proximity to the proposed wharves at the Zwartkops was inestimable, especially in connection with the timber trade to the interior. The Zwartkops River was undoubtedly the natural site for the formation of a harbour for Port Elizabeth, and were that town springing into existence now—in the days of the modern sand-pump dredger which rendered the opening of such rivers possible—there could be little doubt that the position chosen would be at the Zwartkops River. South Africa was but in its infancy, and so was each of its few ports, including Port Elizabeth. Looking to the growth of the community, it would therefore appear to the Author unwise to allow the vested interests of the moment to govern too largely the future policy of development, and to force it into a scheme not only costly and defective as regarded lack of storage-space, but also, as the Author believed, by no means certain of success. It was true that the eastern arm of the proposed harbour was intended to be left open at its shoreward end; but the western arm was a solid work, and a harbour of this nature, constructed across a sandy foreshore where, as Mr. Matthews had said, the sand travel was very active, though now partly reduced so far as wind-blown sand was concerned, was almost certain to cause large accumulations of sand on both sides of it, with an advancement of the foreshore and reduction of the depths of water. No doubt sand-pump dredgers might keep down any accumulations of sand on the inside of the harbour, but they would be unable to prevent such a shoaling to the eastward as that alluded to. In 1890 a detached breakwater was proposed opposite the town in 30 to 33 feet of water, but the proposal was condemned by a commission of engineers in London, on the ground that it "would interfere with and prejudicially impede the sand travel along the shore, and cause accumulations in front of

The Author.

the town." Although the action of a work such as this was of course different from that of works projected across the littoral, the Author was of opinion that the latter were equally liable, if not more so, to cause an advance of the foreshore on both sides, and an accompanying diminution of depth ultimately affecting the entrance. The same shoaling influences, it might be urged, would follow on the projection of the entrance-breakwaters at the Zwartkops River, but these works would be comparatively insignificant in extent as compared with the two great arms of the proposed harbour in front of the town, and less difficulty would probably be experienced in maintaining navigable depths between and in front of them by dredging, aided by the scour from the river, than at East London or Durban. At the latter port the average depth on the bar at low water of spring-tides for 1905 was 28 feet 8 inches. The Author could not agree with Mr. Woodford Pilkington that the use of the Zwartkops River was impracticable because it faced south-east. Severe south-easterly gales were only occasional, and were gales from the east or south-east to form an impracticable barrier to the opening of harbours on this coast, the harbours of East London and Durban would not be in existence. It would be difficult to picture any two sand-barred harbours which in their earlier days looked more hopeless. Before the extension of the north pier and subsequent dredging-operations, the Author had walked dry-shod on the bar at Durban just within the end of the breakwater where there was now a depth of about 28 feet at low water. As Mr. Matthews had pointed out, however, Durban was fortunate in possessing a much more effective backwater than East London, the scour from which, directed by the north pier, had greatly assisted the work of the dredgers. The Author hardly thought that Mr. Gonsalves was justified in assuming that because the Paper dealt only with the harbours on the south-east coast, it might lead to the inference that no harbours existed on the west coast. The Paper dealt with the harbours between Cape Town and Delagoa Bay, these being the cases with which the Author had been professionally connected. In addition to Lobito Bay, there was, indeed, only about 80 miles northward from Cape Town, Saldanha Bay,[1] a very fine natural harbour with great capabilities, and proposals for its development were, he believed, at present under consideration. With regard to Mr. Tripp's desire to know the effect of the freshet of the 9th, 10th and 11th October, 1905, on the mouth of the Buffalo River at East London, the Author had ascertained from Mr. J. W Sowarsby, M. Inst. C.E., the Resident Harbour Engineer at East

[1] See *post*, p. 66.—SEC. INST. C.E.

The Author. London, that the narrow portion of the river within the entrance had been scoured out from 22 feet to 32 feet deep, and that the entrance had been scoured down until a hard bottom was reached. Such effects, however, were only temporary, and the Author had always held that in the inception of harbour-works in South Africa it was unwise to place any reliance on freshets as scouring-agents, and that only the tidal volume, and the normal amount of upland waters, should be considered as available for scouring. Freshets were exceedingly variable in South Africa, and the main consideration in connection with them was the protection of shipping in the harbours from their violence. The Author entirely shared the views of Mr. Elliott-Cooper with regard to the capabilities of Port Alfred and the great advantage it possessed over East London in the large areas of flat land on both sides of the river. The beach immediately to the west of the entrance, however, held immense volumes of sand, which was not the case at East London, and this might throw a greater strain on any dredging-plant employed to keep the entrance open. Mr. Elliott-Cooper was in error in stating that the largest steamers now went into East London. The mail-boats now regularly entered Durban Harbour, but the conditions of the entrance at East London had not yet rendered this a safe operation. With regard to the general lines of the design of the entrance-works at Durban, and the forces which were acting there, as to which Mr. Colson and Mr. Meldrum thought further information would be of use, the Author, although he stopped further extension of the Durban breakwater in 1892 until the north pier could be brought up, held that both works should be extended 600 feet, in order to reduce dredging to a minimum. His reasons were given in the Paper (pp. 38 and 39). He was not responsible for the points from which the two entrance-works were started, and was of opinion that equally good results would have been attained with shorter works had the breakwater been started from a point farther to the south-east and the north pier from a point farther to the north, the two works converging at their outer ends. The inducement to start the breakwater from the point where its present root was situated had been a reef of rocks extending a short distance into the sea, and a desire not to receive the seas so square on to the work. With regard to the forces at work about the entrance, and the changes which took place from year to year, the Author had made the fullest investigations, and many of the diagrams of these were to be found in the valuable report on Durban Harbour by Sir Charles Hartley and Sir John Wolfe Barry, dated 15th April, 1897. Generally, it might be stated that the prevailing winds were from N.N.E. to

E.S.E. and from S.S.E. to W. The prevailing seas were from southerly to south-easterly directions, and these, wheeling round, crossed the entrance about east to west. Seas from southerly directions tended to increase the bar and those from north-easterly to easterly directions usually assisted the action of the tides in lowering it. The prevailing littoral current flowed from south to north, and its velocity seldom exceeded about ½ knot per hour; it was therefore not of sufficient velocity to materially affect the case. The sea-bottom was for the most part sand, and the beach for about 100 miles south of the entrance was heavily charged with it. The rise of tide at springs was 6 feet, and the tidal volume a few years ago would be about 25,000,000 cubic yards. The Author had never been of opinion that a single curved breakwater such as that described by Mr. Meldrum would be successful at Durban. It was possible that such a breakwater in conjunction with the north pier, as in the scheme proposed by Sir John Coode in 1870, would have been more or less successful, but the aspect of the entrance was too far to the north. Any solid work, curved or otherwise, projected seaward from the end of the Bluff, alone and without a northerly work of at least equal length, could only result, as the present breakwater had resulted when projected too far beyond the north pier, in collecting sand under its lee and finally blocking the entrance. The Author.

Correspondence.

Mr. W. Dyce Cay had been much struck with the similarity of the problems and conditions of the harbours of South Africa to those he had had to deal with in the improvement of the entrance at Aberdeen, and of its bar and channel. The drawing of East London harbour at the mouth of the Buffalo River (*Fig. 7*) was almost identical with the Aberdeen design, though of later date, the Aberdeen parliamentary plans having been lodged in 1867. This similarity, and the wonderful success of Aberdeen harbour, led him to remark on the plan of East London shown in *Fig. 7*. One feature was the want of spending beach in the river, and the contraction, mentioned as a defect in the Paper, caused by a south pier or wharf near the entrance, at a point only 200 yards landward of the sea at the end of the east pier. At Aberdeen the works on the south side, the old south pier and the old breakwater, were removed, so that measuring from the open sea at the end of the north pier, Mr. Dyce Cay.

Mr. Dyce Cay. which, as in *Fig. 7*, was not so far seaward as the end of the south breakwater, the distance or length of spending beach was 730 yards; while measuring from the root of the new south breakwater, the length was ½ mile. With regard to the general question of sand-bars, he had no doubt that the source of the sand was the erosion of river-floods on their catchment-areas; when the sand reached the sea the waves and currents took charge of it and sorted it, the fine mud finding a resting-place in the greater depths, while the ordinary sand was thrown up to form beaches and bars—which were submarine beaches; and from the beaches it was blown inshore by the wind and formed dunes and sand-hills. The sand on a bar contained a large proportion of comminuted shell, yet he had found, on agitating it in a beaker, that it settled at once to the bottom when the motion was stopped, so that it was heavy, and moderate currents did not have much effect on it, unless assisted by the friction of passing waves. This river- and wave-action had proceeded for geological ages, so that if the present supply of river-sand were stopped, the wind and waves would still have material to work on; but not so much, because, without fresh material a state of equilibrium would be reached, when the beaches would become more stable. On these grounds he had advocated in river-harbours, where the conditions admitted, that the river should be diverted and separated from the navigation-channel and entrance of the harbour, keeping it on the lee side of the harbour as regarded the prevailing sea-current outside. This would also save the enormous dredging, in the interior of the harbour, of detritus brought down by the river and caught by the deep pools dredged in it to form the harbour—which seemed to increase in amount with the progress of the deepening. Another point was that the sea should not be allowed to break at one place, but as far as possible the breaking of the sea entering the harbour-mouth should take place gradually by allowing it space to expand like a fan; the advantage of this lay in the fact that the sand was transported by the united action of the sea-wave and current, and if the sea-wave ceased suddenly, the sand at once fell to the bottom and formed a bar. This was a reason why a bar, once formed, added to itself, as it broke the sea; and showed why a channel dredged through the bar, and attended to, had such favourable results.

Dr. Corthell. Dr. E. L. Corthell observed that the difficult conditions along the South African coast under consideration appeared to be, first, severe exposures, and secondly, rivers of only small size discharging directly into the sea, or through lagoons and cordons of sand-bars shifting with the winds. The works with which he had had to do, in their construction and in the maintenance of the channels

created by them, had great support from large fluvial volumes; and the work for which he was now acting as adviser in Rio Grande do Sul, Brazil, were similarly and even more fortunately situated, being at the mouth of an immense lagoon which received the discharge of nearly 900 miles of navigable river (a watershed of about 83,000 square miles), the lagoons themselves covering 94,000 square miles, and having a mean range of tide of about 4 feet. These conditions would necessitate very little dredging, if any, in order to increase the depth over the bar from 13 feet to 34 feet; but nowhere along the coast described by the Author were there any such favourable conditions, and Dr. Corthell was of opinion that dredging needed to be resorted to in large measure to produce and to maintain the channels. However, he would like to ask the Author's opinion as to the results—had both works at Durban been pushed as actively as possible at the outset, parallel and 600 feet apart, straight out to, say, the 30-foot depth in the sea beyond the bar? From his own experience, he was strongly of opinion that the secret of success in such works was rapidity of construction, assuming, of course, that the works were correctly situated. He believed the general fault, as in the case under discussion, was too great width, the Durban works having been narrowed from 900 feet to 800 feet, then to 700 feet, and finally, under the advice of Sir Charles Hartley and Sir John Wolfe Barry, to 600 feet. Dr. Corthell considered that this fact had a very important bearing upon the question. Training-works were rarely situated too near each other, and generally they were too far apart. He would like to ask the Author for the details of the cost of dredging given on p. 43 as varying between "a little more than 1*d*. per ton and 3*d*. per ton," in order to know what entered into that cost, and particularly whether cost of plant, interest on the cost, depreciation, repairs, general administration, etc., were included. He would also like to know what was the relation between a ton of material dredged and a cubic yard in place in the excavation; whether the material was carried away to the spoil-banks in the hulls of the dredgers, or in hopper-barges; and whether the barges were self moving or towed, or if the material was pumped through pipes. With those details, and not otherwise, could an idea be formed of the real cost, or the latter be compared with the cost elsewhere. He was in full accord with the Author's conclusions that the first duty of the engineer was to see that, in the disposition of the works, he utilized to the utmost degree, and in the most effective and economical manner, any natural forces available, so as to minimize the amount of dredging necessary, and that it was here that the problem was as great as ever. It was often the idea among engineers that because dredging was done

Dr. Corthell.

Dr. Corthell. nowadays very cheaply, the more of it the better. He had combatted this idea with strong insistence in the project for the present works for deepening the channel through the bar at the mouth of the South-West Pass of the Mississippi. There, with properly situated works, no dredging whatever would have been necessary, but by the plan proposed many million cubic yards would have been required to make the channel, and maintenance would have required endless dredging. He was glad to say that the plans had been very considerably modified, the jetties having been made more nearly parallel, thus reducing the great width at certain points.

Mr. Eliot. Mr. WHATELY ELIOT, having been the Resident Engineer in charge of the harbour-works at East London from 1880 to 1885, could bear testimony to the exceptional difficulties, due to the site and local circumstances, which had had to be taken into account by the late Sir John Coode in the design of the works at the entrance to the Buffalo River, and also to the very tedious and difficult work experienced in the construction of the protecting breakwaters, due to the shifting sand and almost continual heavy seas. The prevailing winds at East London were from W.S.W. and E.N.E. Strong winds and gales from W.S.W. were prevalent more or less during the whole year, and caused very heavy rollers from the south. Strong winds from E.N.E. were most frequent from November to April and brought in a short broken sea; these winds never lasted more than 2 or 3 days at a time. The changes of wind were sudden and frequent. A strong current set to south-west along this coast, varying in strength between 1 and 3 knots per hour according to the state of the sea. The range of the tides was 5 feet 3 inches at ordinary spring-tides and 1 foot 10 inches at ordinary neap-tides. The Buffalo River, as far as the tide flowed inland, might be considered as simply a tidal estuary, for the flow from the river was very small except in times of unusual rainfall, which in past years had caused heavy floods. These floods came down the river with such force as to clear all the sand from inside the harbour. This sand on reaching the sea was driven by the surf on to the shore north of the entrance, whence it was washed back again by the sea as soon as the flood subsided. The first flood of which there was a record was in 1848, at which time sandbanks extended 1 mile up from the entrance, with a small, shallow, and winding channel at low water. The whole of this sand was driven out by the flood. From the shape of the entrance, which widened as the sea was reached, the sand was forced back again by the sea, and by the time of the next flood, in 1863, it had accumulated to the same extent as in 1848. The sand was again removed by the flood, and again returned. Floods occurred

in 1871, 1872, 1874, and 1876, with similar results. By this time considerable progress had been made with the training-walls, and the protective works at the entrance had been begun; and as no floods of any importance occurred for more than 10 years, any improvement in the condition of the harbour and entrance during that period must be due entirely to the works that had been carried out. Although the scour of the tide was found to be insufficient to maintain a channel of more than 4 to 5 feet in depth at low water in the lower part of the harbour, the sand was kept in check and prevented from reaching the upper part of the harbour as it had done in former years. There did not appear to have been a serious flood since 1876 until October, 1905, when 11½ inches of rain fell in 53 hours and caused a most alarming flood. The shipping in the harbour seemed to have escaped damage in a marvellous manner, considering that a quantity of floating debris was carried down by the flood. It would be interesting if the Author could state what effect this latest flood has had on the depth of water at the entrance. Reference had been made to the difficulties encountered in constructing the south breakwater, on account of the frequent heavy seas interrupting the work. The average number of days in each year on which work on the breakwater had been possible was 147, and on only 60 of these days could work be continued throughout the whole day. The work, however, had been carried out to its full extent and into comparatively deep water in 1885. During the construction of the south and east breakwaters it was observed that each year, during the months of May and June, a bank of sand formed off the south breakwater, and disappeared again a few months later, when the rollers were not so heavy. It was evident, from observations taken at the time, that the material which occasioned this shoaling was chiefly derived from the sand accumulated in the bight immediately northward of the east breakwater. Whenever the surf was strong enough to create a current moving seaward out of this bight, the current charged with sand passed out along the back of the east breakwater, and across the entrance until, being met by the broken seas off the end of the south breakwater, it was checked and there deposited the sand. Perhaps the Author could state whether the extensive dredging during recent years had decreased this periodical shoaling, or whether it would be necessary to prevent it by the construction of outer works. It was evident from *Fig.* 7 that the sand-pump dredgers, which had been at work since the south breakwater was completed, had had a most beneficial effect on the entrance by the removal of sand. It remained now to improve that part of the entrance where the navigation was rendered Mr. Eliot.

Mr. Eliot. difficult through the narrow width of the channel between the training-walls, and this no doubt would form an important part of the future development of the port.

Mr. Heenan. Mr. R. H. HAMMERSLEY HEENAN remarked that the Author was not quite accurate in some of his statements. As far back as 1891 Mr. Heenan had reported to the Port Elizabeth Harbour Board his opinion that by far the greater quantity of sand travelling round the littoral was driven into the bay from the dunes to the southward during south-west gales, and that if these dunes could be permanently fixed by vegetation or otherwise, the sand-travel would not present any insuperable difficulty to the construction of a solid breakwater from the shore. The Harbour Commissioners authorized him to submit his views to Sir John Coode, with a view to obtain his opinion on the subject. This was done, and Sir John, while still objecting to solid works projected from the shore, strongly supported the fixing of the dunes, as he realized they were a menace to any solid works that might be constructed. Shortly after this, the Government, with the assistance of the Harbour Board, and other local bodies, undertook the reclamation of the sand-drifts, and in a few years those along the littoral were completely fixed. In 1896 Mr. Heenan, as Engineer-in-Chief to the Board, suggested to the Harbour Commissioners that the time had arrived when sheltering works on a large scale should be undertaken, and expressed the opinion that, as the supply of sand from the dunes was then cut off, a breakwater might safely be carried into deep water almost at right-angles to the shore, without any danger of its being enveloped in sand as the original work had been, provided the structure terminated in at least 7 fathoms of water. In making this proposal he was influenced by the fact that the quantity of sand that had accumulated round small groynes thrown out for temporary purposes was such as to be easily removable at a small expense. The Commissioners favourably considered this suggestion, and he was authorized by the Board and by the Government to submit his proposals to Messrs. Coode, Son and Matthews. He discussed the matter fully with them, with the result that they prepared a scheme on the lines suggested, but with the important modification that instead of having the southern breakwater solid from the shore they provided for its commencing some distance from the shore, approached by an open iron viaduct. On returning to the Colony, Mr. Heenan recommended that an experienced engineer, with assistants, should be placed on his staff, to make an extensive series of observations with regard to currents, sand-travel, and sand-disturbance generally. This recommendation having been sanctioned

by the Harbour Board and approved by Government, he arranged for the appointment of the late Mr. Alexander Brebner, and gave him detailed instructions how to proceed. After about 20 months of close observation, Mr. Brebner reported in the terms mentioned by the Author. Mr. Heenan.

Commander F. W. JARRAD, R.N., remarked that the Paper was of especial interest to him, inasmuch as he had visited some of the ports of South Africa as far back as 1867 in H.M. surveying-vessel "Hydra," and had seen Durban Bay, now named Port Natal, when it was nothing more than a shallow lagoon inaccessible to all but the smallest craft. At the time of the "Hydra's" visit there was only sufficient water on the bar to admit of the crossing of a small steam-tug, drawing 6 or 7 feet. The "Hydra," which drew about 12½ feet, had to remain at anchor in the roadstead, where, owing to the heavy ground swell from the south-east and the vessel riding to a north-east wind, the most uncomfortable time imaginable was spent. Some attempt had then been made to improve the entrance by constructing a rough groyne on the sand-spit (north side), but with no beneficial result; and the work had been discontinued. The local authorities consulted the commander of the "Hydra," Captain P. F. Shortland, R.N., who, after inspecting the bar and lagoon, was of opinion that a much more extended investigation must be made into the exact effect of the currents in transporting and depositing sand, under all the varying conditions of wind and sea, than had hitherto been conducted, or than the surveying-vessel's short stay would admit of undertaking; and until that had been done neither he nor anyone else could form a correct opinion as to the most suitable design for improvement-works, though he considered them to be feasible. Nothing could better illustrate the soundness of these views than the account the Author gave of the quantities dredged from the bar, and the corresponding depths obtained each year from 1897 to 1904, which proved that the depth obtained was not in proportion to the quantity removed but depended, as the Author said, on "the uncertainties of weather and the consequent movement and deposition of sand." The creation of a first-class port out of such unpromising material as the bar and shallow lagoon at Durban presented in 1867 was not then deemed possible, and it was a feat of which the Author, as engineer-in-charge of the works during the greater part of the time, might well be proud; and although it might be said it could never have been achieved but for the invention of the suction-dredger and the great development of its capabilities in recent years, yet, as the Author pointed out, even the best dredging-appliances could not always contend Commander Jarrad.

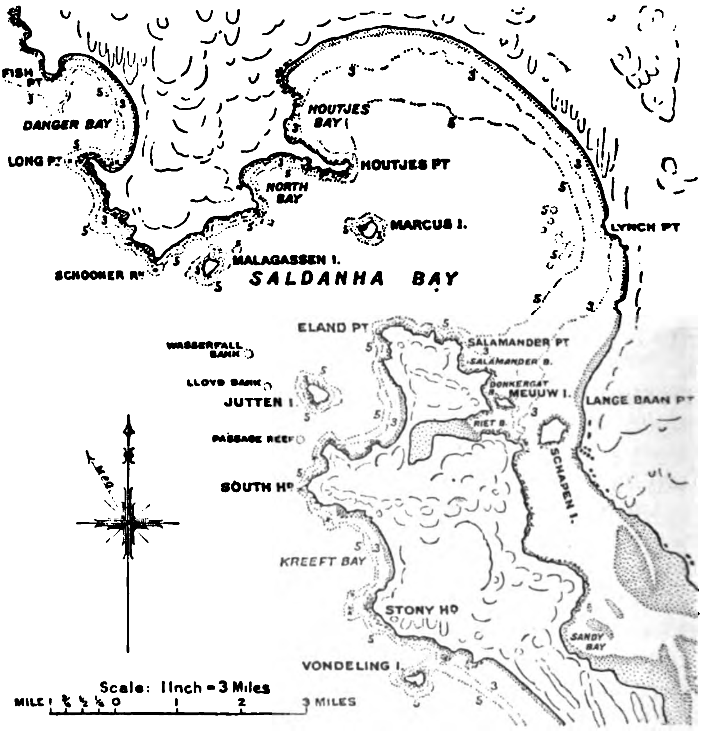
Commander Jarrad. against the physical forces which promoted the deposition of sand unless every particular of their mysterious working had been thoroughly investigated and ascertained. The success of the works at Port Natal appeared, therefore, to be really due mainly to the thorough investigation which the Author had made of all the circumstances connected with the movement and deposition of sand forming the bar. It was generally conceded by engineers that however much the general features of one place might resemble those of another, there were always some subtle effects of wave- or current-action peculiar to each place which rendered it impossible to apply the same scheme of improvement works in any two cases with the certainty that they would both prove successful; yet Port Natal harbour-works presented an object-lesson in dealing with lagoon outlets of this type. Detailed information of all the special local conditions obtained during the Author's long residence there would thus be of the greatest value to engineers and others who might be interested in bringing about a like measure of improved access to lagoon entrances of a similar type elsewhere. Many such existed on the coasts of peninsular India, the opening up of which to vessels of greater draught might at any moment become desirable under the changing conditions of trade routes brought about by railway-development. The capabilities of development presented by such places, similar in type to these African harbours, such as Cochin on the west and Vizagapatam on the east (though the latter's capacity had been much interfered with by injudicious reclamation), had been pointed out years ago by such well-known engineers as the late Mr. S. B. Parkes, the late Mr. Horace Bell, and, as regarded Vizagapatam, by Sir Alexander Rendel. The success which had been attained at Port Natal should go far to prove the feasibility of developing these skeleton harbours into subsidiary ports when it was deemed necessary. No mention was made of the cost of the works at Port Natal except in respect to the dredging-operations, and it was hoped that the Author might be able to supplement the valuable information contained in the Paper by some further details as to the cost of the breakwater and the north pier, and also as to the estimated yearly cost of dredging in order to maintain the necessary depth at the entrance. Another question often raised in connection with works which involved increasing the tidal volume, while at the same time confining the current to a narrower entrance, was whether or not the increased velocity would be such as to render the navigation difficult or dangerous. The maximum rate of the ebb-current between the piers was understood to be 3½ knots per

hour, and of the flood 2½ knots. It would be interesting to know how long on each tide this maximum rate was maintained. Some extravagant predictions had frequently been made on this point, as well as of the inconvenience likely to follow on the entrance being open to the effect of heavy seas. Perhaps the Author could say how far this was the case at Port Natal? On surf-beaten sandy beaches, subject to tidal or littoral-drift currents, a more or less heavily silt-laden distinct belt of water was found travelling parallel with the coast at a distance from the shore depending—when other things were equal—on the slope of the bottom and the length of the surf-wave; and as the 10-fathom line approached within 600 yards of the coast south of the Durban bluff, the sand-travel might have been expected to pass close round it, as *Fig. 9* would imply was the case. Did the Author think that, if he had to design works to meet now what was originally the case as shown in *Fig. 9*, any modification could be made in the length of the south breakwater and consequently of the north pier, having regard to his experience of the capability of the suction-dredger? This inquiry was made simply with a view to ascertain whether the cost of the piers at Durban was at all comparable with what it might cost now to bring about the same measure of improvement in a similar case. Commander Jarrad.

Mr. CHARLES NEATE mentioned that he had visited the East Coast of South Africa in 1869 in order to collect data for reports on proposed east-coast harbours which Sir John Coode was engaged to present to the Colonial Government. Of the four ports which he then visited—Port Elizabeth, Port Alfred, East London and Durban—East London had appeared to him to be one of the most promising. The depth of water outside the harbour had been rather greater, and the sand-travel had appeared to be rather less, than at other points of the coast. He had also thought that something was to be hoped for from the scouring effect of the freshets, which at that period were observed to occur every few years. He believed that the designs for harbours on this coast presented by Sir John Coode were as likely to prove successful in execution as any that could be devised; but the local conditions prevailing along the coast were such that it seemed doubtful whether any harbour-works could be designed which would secure the automatic maintenance of a deep-water channel to the harbour-entrances. At the period of his visit suction-dredgers were unknown, and there could be little doubt that their introduction had been a powerful factor in the maintenance of the South African harbours. Mr. Neate.

Mr. Olive. Mr. W. T. Olive was somewhat surprised that no mention was made in the Paper of the splendid natural land-locked harbour at Saldanha Bay on the south-west coast, 60 miles to the north of Cape Town. When he visited it some years ago, he formed the opinion that at a comparatively small expense perfect accommodation could be obtained. This would readily be apparent from a glance at *Fig. 17*. The chief drawback was the want of a good water-supply; this raised

Fig. 17.



Saldanha Bay.

a difficulty, but by no means an insuperable one. With regard to Cape Town, on the 9th July, 1900, after studying the various discussions of the Cape Town Chamber of Commerce and the Harbour Board on the unsatisfactory state of matters at the docks, which had then reached an acute stage, Mr. Olive prepared a scheme indicating the main lines on which future development should, in his opinion, proceed; and he felt justified in submitting his views to a select

committee of the House of Assembly appointed 7th August, 1900, to inquire into the financial position and working of the harbours of the Colony; for which he received the thanks of the committee in due course. Briefly stated, his proposal was to construct, parallel to the South Pier and about 2,000 feet south of it, a trunk wharf of ample breadth, with proper screenage on the south and east sides, which would not in the first instance be used for berthage on those sides. This wharf would extend to about the 5-fathom line, about 3,500 feet out into the bay, and would have on the north side parallel branch piers or jetties, about 350 feet apart and making an angle of about 45° with the trunk wharf. The breadth of the main wharf would be 300 feet and that of the jetties 150 feet. Similar jetties could be built on the south side when an extension was required. After digesting the report of the committee with the evidence given, and considering the joint scheme propounded by Messrs. Heenan and Methven, he was still of opinion that the latter, as published in *The Engineer*,[1] was on altogether too extensive a scale (it included a new basin of 431 acres in addition to the existing 72½ acres) to be warranted by the prospective trade of the port. In support of this opinion it might be mentioned that the President of the Port Elizabeth Chamber of Commerce, referring to the tonnage for the past year (1905) dealt with at the various South African ports for the Transvaal and Orange River Colony, had called attention particularly to the Transvaal tonnage; the Cape ports sent 115,000 tons, whereas Durban sent 276,000 tons and Delagoa Bay 390,000 tons.[2] This, Mr. Olive considered, would continue to be the case in an ever-increasing degree, inasmuch as Cape Town was handicapped by having to send its goods over so excessive a length of railway. Was the cost of this scheme (£3,500,000) warranted? As to Mossel Bay, he quite agreed that the back country was not likely to develop in a way to justify heavy expenditure at that port, although it was situated midway between Table Bay and Algoa Bay, and should be, from its geographical position, the natural port for the central coastal divisions of the Colony. The wharfage-receipts for 1897 were £1,732. But it certainly was not a good site for a harbour, as it was much exposed, especially between east and south-east. The prevailing winds were west in winter and south-east in summer, and the tide ranged 6 feet. The general trend of the current was south-east to Seal Island, where it divided and returned in the opposite direction. With regard to Port Elizabeth, he did not favour Mr. Olive.

[1] Vol. xciv (1902), p. 276.

[2] *The Cape Times*, 5 May, 1906.

Mr. Olive. the proposal for the opening up of the Zwartkops River, because the proposed works would be about 6 miles to the north of the town, and vested interests had for too long been localized at the Baakens River; and as to the plea of the value of reclaimed land justifying it, he would observe that there was any quantity of land to be had without the cost of making, in the neighbourhood nearer the town. The plan proposed by Sir John Coode in 1877 was estimated to cost £930,000, and it might be further considered by those interested, as against the joint scheme of the recent commission of engineers, estimated to cost £3,100,000. The effect of winds in causing sand to drift was generally under-estimated. Mr. Hammersley Heenan had stated that during the last 25 years many thousand tons of sand had been blown into Algoa Bay.[1] Again, the Port Alfred southern pier, built about 1880, was found to be entirely buried for a considerable length by sand in 1900, and works costing £250,000 were practically abandoned. Mr. Olive had never landed at St. Lucia River in Zululand, but had heard that the swampy region at the mouth of the Umvolosi was uninhabitable, or, at any rate, not fit for a white man to live in. Without dogmatizing, it might be said generally that in many works like those under discussion the amount of tidal water admitted should be jealously guarded, so that no diminution might take place, otherwise a reduction of the scouring effect at ebb-tides would be a natural consequence. He had never known this question more logically thrashed out than by the opponents to the Manchester Ship-Canal Bill in its early stages in connection with the estuary of the Mersey. With regard to Durban, under the present conditions of these works, continuous dredging would be necessary, and he had seen by the port's dredging-plant that efficient means were being provided to cope with this. Suction-dredgers were suited to Durban, and it was evident that the work there was being done at an exceptionally low cost, which, he took it, was exclusive of depreciation, interest, insurance, and superintendence, and did not include the transporting and deposition of dredged material. As to the sheltered conditions of Delagoa Bay, his only experience of landing at Lorenzo Marques was that he could not return to the steamer for many hours on account of the roughness of the water; whilst as regarded its accessibility at all states of the tide, he would mention that on the 1st February, 1904, the steamer in which he was travelling ran aground on leaving this port, immediately after the departure of the pilot, and near to the iron lighthouse at what he took to be the Cockburn Channel.

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[1] Minutes of Proceedings Inst. C.E., vol. cxxx, p. 274.

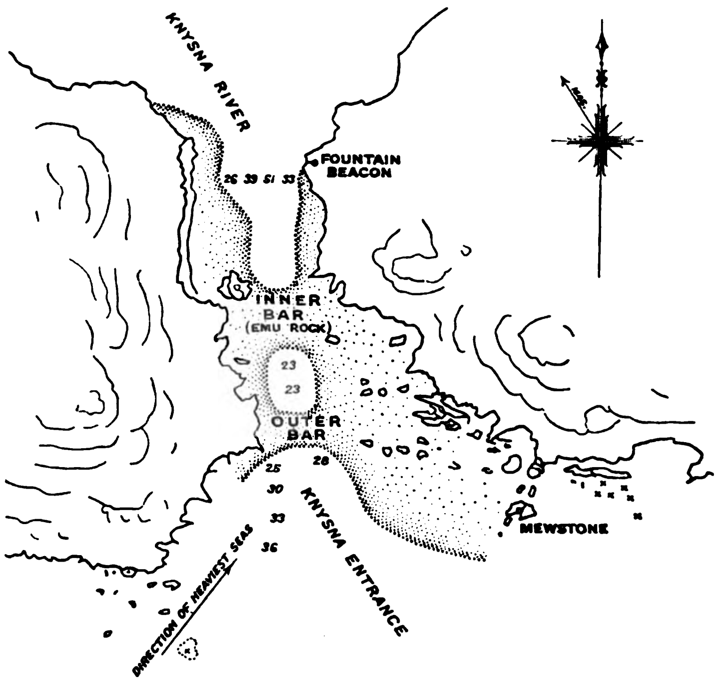
At the time she could not have been drawing more than 18 feet of water; the engines were reversed, and after churning up brown mud for a time she got clear. He thought there was a great future before Lorenzo Marques with proper developments, and he believed that what he had warned Cape Town of 6 years ago was now taking place, namely, the diversion of the trade to that port. In conclusion, he congratulated the Author on the clearness of his Paper. Mr. Olive.

Mr. H. T. H. SICCAMA remarked that the building of harbours on sandy coasts, even where the exposure was moderate, was a difficult problem. In the cases mentioned by the Author there seemed to be additional complications, particularly the exceptionally high rollers on some parts of the South African coasts. The question of what the ratio should be between the static inertia of a mass of concrete or masonry and the dynamic force exerted by a wave of translation had not as yet been accurately ascertained. The rule of thumb that the weight of a block should be not less than twice the weight of a mass of water equal to the cube of half the wave-height did not hold good if the length, breadth, and height of such a block differed much from each other. With a wave-height of 30 feet and a material weighing 1 cwt. per cubic foot, a solid block would have to weigh 160 to 180 tons, and twice this if the length were twice the breadth and height. The late Mr. Thomas Stevenson mentioned a case at Wick breakwater, where a solid mass of 1,350 tons had been moved by the waves during a gale, but did not mention the height of the waves in this instance. The waves in the North Sea on the Dutch coast rarely attained 10 feet in height during south-west or north-west gales, and yet on the Ymuiden breakwater a slab of 300 tons had been slued round. It was therefore difficult to fix the limit of safety. In theory it was possible to place or cast in situ large masses of concrete, in bags for instance, or in caissons; but then again arose the question of cost, which increased more or less as the square of the size of the blocks used, even when these numbered thousands. Again, submerged sand-beds were very irregular in density over small areas, and the settlement under heavy superimposed loads was often apparently capricious. Mr. Siccama

Mr. F. W. WALDRON had had the honour of being associated, on behalf of the Colonial Government, with the Author during his investigations of the harbours of St. John's, Port Alfred and Mossel Bay, all of which were more or less subject to troubles due to the sand, and he was quite in accord with the Author as to the causes of the formation of sand-bars. From an experience of 30 years upon the south-east Mr. Waldron.

Mr. Waldron. and south-west coasts, he was of opinion that the only remedy was dredging, in conjunction with judicious training of inner banks in the case of rivers. There was one harbour on the South African coast, however, which the Author had not touched upon—possibly because he might not have visited it—namely, Knysna (*Fig. 18*). Knysna, as shown in *Fig. 1*, was the next port to Mossel Bay, and was situated about 60 miles eastward thereof; the entrance was naturally

Fig. 18.



KNYSNA.

protected from the south-west seas, but open to the south-east. The tidal compartment extended about 8 or 10 miles inland, and the scour caused by a considerable tidal volume collected upon a large area of sandy flats inside the harbour had the effect of preventing the deposition of sand at the narrowed portion of the entrance near the Fountain beacon. The depths at this point were 40 to 50 feet at low water; then the water gradually shoaled until the inner bar was reached, upon which a depth of only 13 feet existed; the water then

Mr. Waldron.

increased in depth to about 22 feet, and again shoaled to 17 feet 6 inches, forming the outer bar (*Fig. 18*). Much speculation had taken place as to the cause of this formation, and whether the inner bar was due to the existence of a rock barrier beneath. In 1896, while surveying the entrance, he obtained with much difficulty probings on the inner bar to a depth of 5 feet 6 inches; but as this did not reach below the earliest Admiralty soundings taken in 1818 by Captain Walker, R.N., no definite conclusion could be arrived at. The soundings showed 18 feet on the inner bar and 32 feet on the outer bar, so that in the 88 years the amount of silting which had taken place on these two bars was respectively 5 feet and 14 feet 6 inches —not a large quantity in such a period; and the maintenance of the depths referred to must be attributed to the rapid ebb-current inside, and to the effect of eddies caused by a number of isolated rocks on the eastern side of the outer entrance. The only disadvantage to the navigation of the entrance was the occasional violent westerly seas which rendered it impossible for vessels to enter; they therefore had to take shelter at Plettenberg Bay, which lay a few miles to the east. Some years ago the small coasters of the Union and Castle lines regularly entered the river, but of late years the coasting trade had been carried on by a local firm with two steamers, drawing 11 to 12 feet, which ran regularly to Cape Town and Mossel Bay, and occasionally to Port Elizabeth and East London. A considerable trade was done in timber grown in the Knysna forests. No works had been carried out in the harbour other than a small jetty at which the steamers loaded and discharged.

The Author

The AUTHOR, replying to the Correspondence, did not agree with Mr. Dyce Cay's remarks as to the benefit to be derived by diverting any of the rivers under consideration so as to separate them from the navigation-channel and entrance of the harbour. Where their area admitted of it, adjoining lands might with advantage be utilized for docks, so as to remove the shipping out of the main channel, if subject to heavy floods, and leave it unhampered by wharves. This precaution the Author had adopted in his designs for the harbours of Port St. John's and Port Alfred. The rivers of South-East Africa were not, however, as a rule troubled with muddy estuaries or outlets; and silting-up, except on the bars by the action of the seas, did not constitute so grave a danger as floods in time of abnormal rains. The danger was then to shipping in the stream, and not as a rule from silting, for reasons dealt with in the Paper. The diversion of the outlets of rivers falling into lagoons was however another matter, as in some of the larger lagoons, by

The Author. the deposition of detritus, they would ultimately bring about the shoaling up of the lagoons and serious decrease in the tidal volume. Moreover, where dredging-operations had to be resorted to in order to keep open permanently a sand-barred river, the Author was strongly of opinion that any available scour from the tidal compartment of the river, unless quite inconsiderable, should be conserved, if not as an actual scouring agent, at least as a means of carrying away a large amount of material in suspension which would otherwise settle down, and to assist in maintaining the effect of the dredgers. Tidal scour in the case of large lagoons, such as that at Durban, or from extensive tidal compartments in rivers, was of course of great importance in minimizing dredging, and should be utilized to the utmost extent. He quite endorsed, however, Mr. Dyce Cay's remarks as to the value of efficient wave-traps and spending beaches, and in framing his proposals for improving the harbour-entrance at East London, he had made ample provision for this by recommending the removal of a portion of the east pier, and the construction of a new one from a point about 2,000 feet east of the present one. Dr. Corthell's question as to the probable results had both piers at Durban been pushed actively out into 30 feet of water, and also Commander Jarrad's question on a similar point, had been dealt with in the Author's reply to Mr. Colson and Mr. Meldrum in the Discussion. The original width between the piers had been undoubtedly much too great, but any suggestion by the Author in the direction of the reduction of the width or the extension of the northern work had met with so strong an opposition that it had been impossible for him to do more than urge such a course to the utmost extent in his power, which he had done. It was fortunate for the colony that the work had been carried out with the addition of the narrowing advised by Sir Charles Hartley and Sir John Wolfe Barry, and it was still more fortunate that the Author, by stopping further extension of the south breakwater in 1892, and by his subsequent action, had succeeded in preventing the suicidal policy of dredging alone with an extensive and long overlap of the weather work, a policy which could have had but one result, namely, the most hopeless and expensive dredging-operations, and the frequent closing of the port during and after bad weather to all but comparatively small craft. The Author understood that the cost of dredging by the sand-pump dredger quoted as 1*d.* to 3*d.* per ton, did not include depreciation of plant and interest, but included all other charges. Adding this, the cost would range from about 1·54*d.* to 4·10*d.* in the case

The Author.

of the two dredgers whose work was cited. The difference of size and power in the dredgers and the site of the work, however, greatly affected the cost. In the case of the rate of 1·54*d.* the dredger was a good deal larger than the other, and had done much of her work on the bar itself, where the sand lay very free, and the place of deposition at sea could be reached in a much shorter time than by a vessel like the other, whose work lay mainly inside the harbour. The sand dredged was usually reckoned to weigh in the hopper about 1 ton per 20 cubic feet. The dredgers carried their own spoil. The Author was glad to have a further endorsement of the soundness of his views, as to minimizing dredging-operations by the utilization of any natural forces available, by an engineer of Dr. Corthell's great experience. Owing to the cheap rate at which dredging could now be done, the temptation to resort to it without fairly facing the difficulties presented by the problem of fully utilizing available natural forces was greater than before, and the subject was of such importance that the Author offered no apology for quoting his own opinion on it as expressed in reports to the Natal Harbour Board in 1892 and 1893—an opinion which the results at Durban, and Dr. Corthell's experience at the South-West Pass of the Mississippi, had fully justified. The Author had reported thus :—

"If the North Pier is not extended the only course left will be to tax the revenue of the port for all time in order to keep it open as far as possible by dredging, an expedient which will not only be a millstone for ever round the neck of the port, handicapping it severely in the face of competition with other ports such as East London and Delagoa Bay, but will only be temporary and intermittent in its effects according to weather, while it will certainly fail of itself to bring about and maintain with any degree of certainty such a depth as we require to constitute this a first-class port for the accommodation of the large mail steamers."

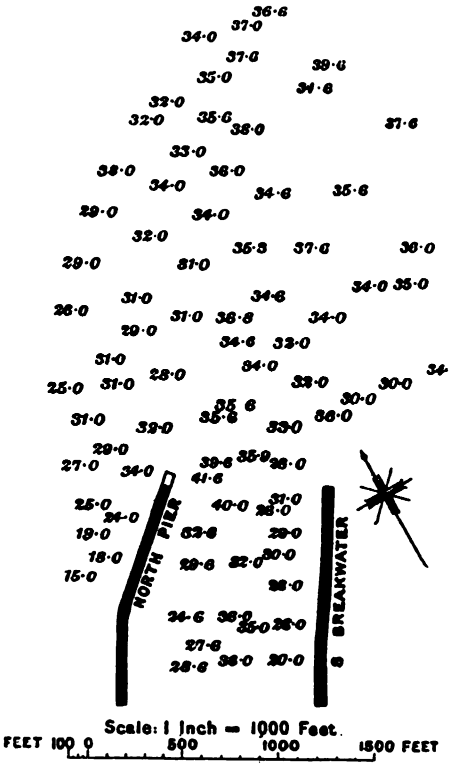
And again :—

"As I have so often said, the time to dredge will be when this can be done to assist nature, by being carried out on the same line, or nearly so, that the tides will follow when properly trained and controlled by the works in a direction as nearly as possible coincident with that of the resultant of the various forces at work."

The most recent official surveys of the bar at Durban dated the 6th June and 5th July, 1906, made by the Engineer's staff, showed a minimum depth of 34 feet at low water of spring-tides in a direct line seaward (*Fig. 19*)—surely a sufficient proof of the soundness of the foregoing views. The Author was informed that the average amount of dredging in the region of the bar was now

The Author. represented by one powerful sand-pump dredger working durir about 7 to 8 months in the year, at an annual cost of £7,000 1 £8,000. The cost of the south breakwater was about £293,00 or only about £110 per lineal foot average cost; but it shoul be noticed that this low cost was largely due to the shoalir and outward movement of the bar which accompanied the extensio

Fig. 19.



DURBAN HARBOUR: DEPTHS AT ENTRANCE, JUNE, 1906.

of the breakwater. The cost of the north pier was about £186,000, or an average cost of about £50 per lineal foot. The cost of the latter work was considerably increased by the unfortunate delay which took place owing to the opposition to its extension, and the consequent formation of very deep water ahead of it (more than 40 feet at low water), which had to be filled up afterwards before

extension could proceed. With regard to Mr. Eliot's remarks as to the eddy-current caused by the surf, which at East London carried sand round the end of the east pier and deposited it on the region of the bar, the Author had observed this action in a very marked degree at Port Alfred also, and it was an argument against running the works in question in the direction given to them, and in favour of constructing the eastern piers at a considerable angle to the entrance. The improvement effected by dredging at East London had been referred to in the Paper. With regard to Mr. Hammersley Heenan's remark in reference to Port Elizabeth, that the Author "was not quite accurate in some of his statements," unless this were as regarded Mr. Heenan's connection with the proposed harbour in front of Port Elizabeth, which he very properly made clear, the Author believed that the whole of his statements were correct, and certainly there was nothing in Mr. Heenan's remarks to prove them otherwise. In reply to Mr. Olive, the Author had omitted mention of the fine natural harbour of Saldanha Bay on the west coast, the general features of which were well known to him, because it was beyond the scope of the Paper, which dealt only with the harbours from Cape Town to Delagoa Bay, inclusive, which had been actually investigated by him. As to the comprehensiveness of the scheme proposed for Table Bay by the Author in conjunction with Mr. Heenan, this scheme was recognized by its joint authors as being far in advance of present requirements, and purposely so, in order that any additional works could be carried out by degrees on its lines. With regard to the opening up of the Zwartkops River at Port Elizabeth, or the construction of works in front of the town, the Author had not discussed in the Paper the relative merits of these two schemes, but he adhered to his opinion as regarded the great value of the contiguous lands at the Zwartkops, the want of which in the other scheme was an obvious weakness; and he could not, in view of the future possibilities of South Africa, and the ultimate welfare and prosperity of the growing population of Port Elizabeth, lose sight of this in favour merely of presently existing vested interests near the Baakens River, referred to by Mr. Olive, to say nothing of the great difference in the cost of, and in the time required for, the execution of the two projects. Mr. Waldron's surmise that the Author had not examined Knysna was correct. The present drawbacks of its entrance as shown on the illustration supplied by Mr. Waldron (*Fig. 18*) were apparent, and the exposure and extremely strong current would probably

The Author.

The Author. render thorough investigation a difficult matter. It was not quite right, however, to assume the difference between soundings taken on the inner and outer bars in 1818 and 1906 to be the measure of the shoaling which had taken place in 88 years, and which, as Mr. Waldron remarked, would certainly not be a large quantity in such a period. In all these cases there was a constant removal as well as a deposition of sand going on, and the later soundings only tended to show what might probably be a minimum sectional area of the channel across the bar naturally maintainable by the outflowing and inflowing tides under the other special physical conditions of the entrance.

10 April, 1906.

Sir ALEXANDER RICHARDSON BINNIE, President, in the Chair.

It was resolved—That Messrs. E. R. Dolby, E. W. Monkhouse, B. Mott, R. J. G. Read, F. Shelford, A. W. Szlumper and T. Frame Thomson be appointed to act as Scrutineers, in accordance with the By-laws, of the ballot for the election of the Council for the year 1906–7.

The Council reported that they had recently transferred to the class of

Member.

JOHN MORGAN PRICE-WILLIAMS.

And had admitted as

Students.

CECIL BOURKE CONNELL.
FRANCIS WALSHE DOWLEY.
RICHARD NATHANIEL MONTGOMERY, B.A., B.A.I. (*Dubl.*)
ARNOLD ALBERT MUSTO.
ARTHUR JOHN POOLE.
FRANCIS HENRY WALKER.

The Scrutineers reported that the following Candidates had been duly elected as

Member.

JAMES WADDELL.

Associate Members.

VIVIAN ELKINGTON, Stud. Inst. C.E.
JOHN IZAT.
JOHN FREDERICK JONES, Stud. Inst. C.E.
NATHANIEL PEARCE.
NILS PERCY PATRICK SANDBERG, Stud Inst. C.E.
ARTHUR GEORGE WILBOND B.E. (*Royal*).

(*Paper No. 3630.*)

"On the Resistance of Iron and Steel to Reversals of Direct Stress."

By THOMAS ERNEST STANTON, D.Sc., M. Inst. C.E., and LEONARD BAIRSTOW.

(*Communicated from the National Physical Laboratory.*)

THE experiments described in this Paper have been undertaken chiefly for the purpose of ascertaining the relative resistances of certain kinds of iron and steel in common use among engineers, when subject to reversals of direct stress. It is hoped that the experimental conditions have sufficiently approximated to those occurring in high-speed machinery to enable the ultimate resistances obtained to be used as a guide in fixing the limits of safe stress in this branch of engineering design.

Jointly with this work a microscopical investigation has been made of the changes which take place in the structure of materials subject to these stresses, as the number of reversals of stress increases; in order to determine as far as possible the lines of weakness in the structure, and the manner in which ultimate failure of the material occurs.

A research on these lines was suggested to, and approved by, the Director of the National Physical Laboratory in 1902. The testing-machine for carrying out the trials was designed, and its construction was undertaken in the workshop of the Engineering Department. The machine was completed in 1904, and the experiments have been in progress since that time.

Previous Work.—The present state of knowledge of the subject is chiefly due to A. Wöhler,[1] whose experiments, made in some cases by repeated loadings of a tensile test-piece between certain limits of stress, and in others by loading the end of a rotating test-piece so

[1] See W. C. Unwin, "The Testing of Materials of Construction," 2nd ed., p. 338. London, 1899.

as to cause equal reversals of bending stress, showed that failure of the test-pieces will occur after some millions of repetitions at stresses which are apparently considerably below the primitive elastic limits of the materials; and further, that the resistances of test-pieces in which the stress varies from tension to compression appears to depend on the range of stress and not upon its maximum value. These results have been confirmed by Professor L. Spangenberg, Professor J. Bauschinger and Sir Benjamin Baker, Past-President Inst. C.E., using machines similar to those employed by Wöhler; and also, in the case of Sir Benjamin Baker's experiments, by a method of bending the test-pieces in opposite directions in one plane. Thus, in the case of rotating bars subject to bending so as to ensure reversals of stress between equal limits in tension and compression, Wöhler found that wrought-iron bars ultimately broke at a stress of approximately 11·5 tons per square inch, and specimens of Krupp steel broke at a stress of approximately 14·3 tons per square inch after a million reversals. Experimenting upon steel by the same method, Sir Benjamin Baker found the corresponding limit after one million reversals of mild steel to be 12·5 tons per square inch and of hard steel to be 15 tons per square inch.

The generally accepted explanation of Wöhler's results on reversals of stress seems to be that suggested by Bauschinger, which is based upon his experiments on the variation of the elastic limit.[1] These experiments showed that the primitive elastic limit of many materials is an artificially raised limit, and that by subjecting specimens to alternate tension and compression several times in succession, the two elastic limits in tension and compression tend to take up definite values, which may be called the natural elastic limits. Bauschinger's suggestion is that the limits of stress obtained in Wöhler's experiments for fracture with an unlimited number of repetitions were the natural elastic limits of the materials, and the results of his experiments appear to confirm this view.

Experiments by Professor Osborne Reynolds, M. Inst. C.E., and Mr. J. H. Smith[2] on reversals of direct stress give results similar to those of previous experimenters, and show further that the resistance of the materials apparently varies considerably with the rate of alternation of the stress when this rate is high. The method adopted was that of using a crank and connecting-rod mechanism with the specimen attached to the slider. In these experiments the limiting ranges

[1] Unwin, "The Testing of Materials of Construction," p. 360.

[2] "On a Throw Testing-Machine for Reversals of Mean Stress." Philosophica Transactions of the Royal Society, vol. cxcix, p. 265.

of stress obtained were considerably lower than those attained by previous observers, which is possibly due to the high rates of alternation employed (1,400 to 2,500 per minute) compared to the rate of approximately 60 per minute used in the Wöhler method. Thus, for mild steel and wrought iron at 1,900 alternations per minute the maximum stresses for an unlimited number of reversals were approximately 6·5 and 6·2 tons per square inch respectively.

Experiments by Professor J. A. Ewing, M. Inst. C.E., and Mr. J. C. W. Humfrey,[1] using the Wöhler method, have shown that failure of the specimens takes place by the gradual development, under repeated reversals, of the "slip-bands" of Professor Ewing and Mr. W. Rosenhain into cracks. These observations were confined to specimens of Swedish iron, but more recently Mr. F. Rogers[2] has studied the development of cracks in specimens of steel under the Wöhler test, which are stated to select a path through the ferritic constituent of the steels. In the same Paper Mr. Rogers described experiments on the resistance of steels which had been subjected to heat-treatment of different kinds.

The Necessity for Further Experiments.—Examination of the previous work which has been done on the fatigue of metals within the elastic limit shows that, although very considerable progress has been made in the knowledge of this department of the strength of materials, much of the information which the designer at the present day chiefly requires appears to be lacking, owing to the following considerations:—

(1) The materials used by Wöhler were not those which are most commonly used at the present time, and most of the recent work having been done on materials which have been "heat-treated" in various ways, the limits of resistance of the ordinary materials now in use are very imperfectly known.

(2) There does not appear to be any general consensus of opinion among engineers as to the kind of material which is best suited for resistance to reversals of stress. As an example of this the use of wrought iron has recently been strongly advocated[3] for the bolts of connecting-rod ends, whereas some engineers strongly condemn it.

(3) Although it appears that the effect of the frequency of the reversals on the resistance is considerable, experiments on reversals

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[1] "The Fracture of Metals under Repeated Alternations of Stress," Philosophical Transactions of the Royal Society, vol. cc, p. 241.

[2] Journal of the Iron and Steel Institute, vol. lxvii (1905), p. 491.

[3] *Engineering*, vol. lxxx (1905), p. 239.

of direct stress at the speeds which are most common in practice do not seem to have been made.

(4) Practically all experiments up to the present time have been made on such forms of specimen as would offer the maximum resistance, although it is often impossible to adopt these forms in practice. Wöhler appears to have found that square corners were a source of weakness; but there does not seem to be any information as to the strength under reversals of stress of such forms as specimens with a screw cut on them, and others in which sudden, or moderately rapid, changes of section occur.

(5) Although from Wöhler's and Bauschinger's experiments there is a strong probability that the resistance depends on the range of stress within certain limits, and not on the actual values of the maximum stresses, further evidence is wanted to confirm this conclusion. This is clear from the consideration that so far comparisons have only been made between the results of bending tests giving equal and opposite values of the stress and tests on the effect of repeated tensions between definite limits.

Objects of the present Research.—For the above reasons it seemed desirable that the present research should attempt as far as possible the experimental determination of:—

(1) The maximum limits of resistance of certain samples of iron and steel commonly used in practice; these samples to be tested in the state in which they are received by machine manufacturers, *i.e.*, without being subjected to heat-treatment of any kind, and at a rate of reversals comparable with that attained in modern high-speed machinery.

(2) The dependence, if any, of the maximum range of stress which the materials will bear for an unlimited number of reversals, upon the actual values of the maximum stresses.

(3) The dependence, if any, of this maximum range of stress upon the other strength-constants of the materials.

(4) The resistances under similar conditions to those stated in (1) of certain forms of these samples, in which sudden and moderately rapid changes of section occur, and the comparison of these resistances with the maximum limits obtained.

(5) The manner in which the materials began to fail, and their subsequent history as revealed by microscopical examination of the structure.

The Testing-Machine in which the Experiments were made.—The resistance experiments have been made in the alternating-stress testing-machine designed and made in the Engineering Department of the National Physical Laboratory, and which has been fully

described elsewhere.[1] For the purposes of the present Paper the following short description of the essential features of this machine may be given, omitting all details of purely mechanical interest.

The machine was constructed on the method adopted by Professor Osborne Reynolds of employing a rotating crank to produce periodic motion of a reciprocating mass by means of a connecting rod, the specimen under test forming the link between the reciprocating mass and the cross-head: in this way reversals of stress are set up in the specimen depending upon the magnitude of the reciprocating mass and the speed of rotation. The modifications in the design of the machine used for the present experiments on that employed by Messrs. Reynolds and Smith are that four cranks operating four specimens are used, and the motion is in a horizontal plane. This is sufficiently indicated in the diagram (*Fig. 1*) which also explains the method of balancing the mechanism.

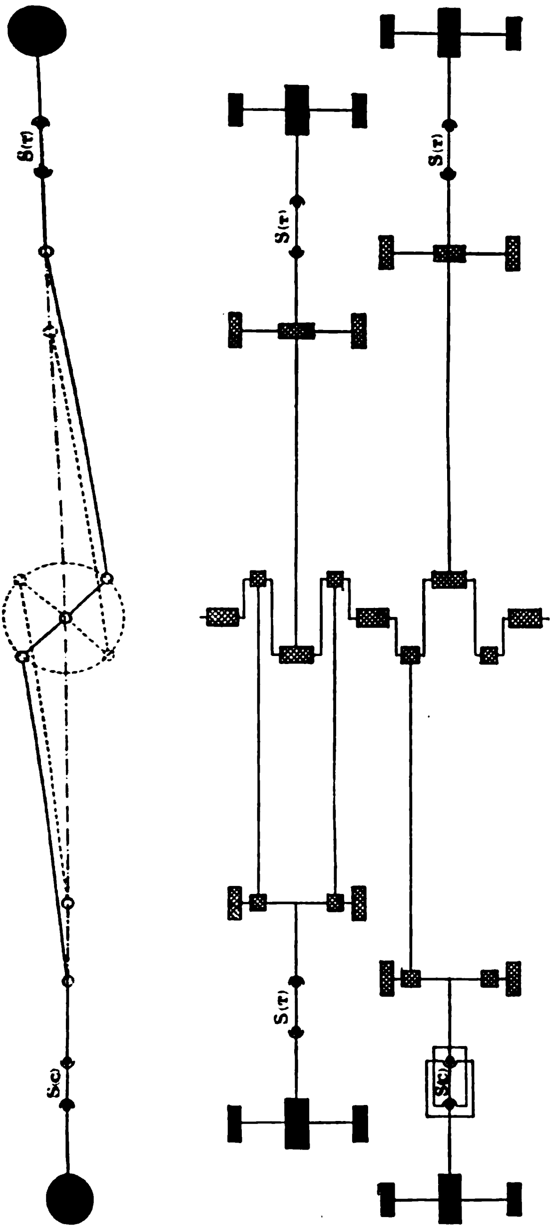
Owing to the comparatively low speed of rotation chosen, *i.e.*, 800 per minute, it was considered necessary to adopt a larger throw of crank than had been used in the experiments at Manchester, the values of the crank-radii being 2 inches and ½ inch in the two cases. As a consequence of this the extreme limits of tensile and compressive stress were not nearly equal in the case of the present experiments, their ratio being 7 : 5. This was not regarded as disadvantageous for the purpose of the work, as this ratio approximates to that actually obtained in steam-engine practice; and further, it was thus possible by fitting to the machine a crank-shaft of smaller throw to obtain the necessary comparisons of the effect of a given range of stress on the endurance of any material when the actual values of the limiting stresses are varied, which is one of the objects stated above.

Owing to the motion of the specimens taking place in a horizontal plane, some difficulty was experienced in controlling the motion of the reciprocating mass after fracture had occurred, so as to prevent the machine being thrown violently out of balance, with possible damage to the remaining specimens.

In order to overcome this difficulty, side-pistons and rods were attached to the main cross-head slippers, the pistons fitting into cylinders bored in the secondary cross-head slippers, the latter forming part of the reciprocating mass. These pistons were set so that in normal running the clearance on each side was 0·03 inch. On the fracture of the specimen taking place, the motion of the reciprocating mass was kept up by the side pistons, the extra motion of 0·03 inch being sufficient to make an electric contact and ring a bell, on which

[1] *Engineering*, vol. lxxix (1905), p. 201.

Fig. 1.



ARRANGEMENT OF TESTING-MACHINE.

the machine was stopped by the attendant and the broken specimen taken out, this being replaced by another specimen or a dummy specimen if no more tests were required.

The machine is driven by an electric motor mounted on the same bed-plate, the whole plate being suspended by four ½-inch steel rods from two overhead beams, so that any inequality in the balance is easily detected. When driven from accumulators the speed is sufficiently constant not to need continual adjustment, but when driven from the ordinary mains an attendant is required to regulate the voltage by means of a carbon resistance. Before commencing these experiments careful observations were made to discover if the friction of the slippers attached to the reciprocating mass had any appreciable effect on the stresses produced in the specimens. The results of the trials showed that the resistance of these slippers varied approximately as the speed, so that the effects of this resistance at the ends of the stroke, where the speed was zero, could be safely neglected.

Although it would have been desirable to complete a test at a single run of the machine, without any stoppage, this was not found practicable in the case of the longer trials, since at the comparatively low speed of the machine only about 400,000 reversals could be made in a single day. Experiments were made in order to discover if a short period of rest of 15 to 20 hours would prolong the life of the specimen, but there were no indications that such was the case. Considerable precautions were taken to prevent any stresses being put on the specimens due to fixing them in the machine. This prohibited the use of lock-nuts at each end of the specimen, the effect of which would have been to set up torsional stresses due to the final locking. The method which was tried, and which proved satisfactory, was to have one end of the specimen locked in the ordinary manner and the other screwed into a long split nut, the locking of which was performed by two set screws in the nut at right angles to its axis.

The greatest care was taken to ensure that the centres of gravity of the two parts of the reciprocating masses, the one ahead of the specimen and the other behind it, should both lie in the axis of the specimen. To do this both parts were balanced independently on knife-edges, and then coupled by means of a specimen, and re-balanced about the axis of the specimen. To minimize the risk of a frictional effect due to the resistance of the slippers supporting the reciprocating mass attached to the end of the specimen, the oil-supply to the bottom side of these slippers was under a head of about 10 feet, so that a state of complete lubrication was ensured.

Materials used in the Research.—These may be conveniently divided into three groups:—

(1) A set of three samples of Swedish Bessemer steels, presented by Mr. R. A. Hadfield, M. Inst. C.E., for the purpose of the work. The carbon content of these steels is approximately 0·17, 0·44 and 0·64 per cent.

(2) A set of four samples of steel, presented by Messrs. Belliss and Morcom, and selected haphazard from their stock:—

(*a*) A piston-rod steel in the form of a bar $\frac{7}{8}$ inch in diameter.

(*b*) A mild-steel bar $\frac{7}{8}$ inch in diameter.

(*c*) Specimens of mild steel cut from a large forging.

(*d*) Specimens cut from a mild-steel bar $2\frac{1}{2}$ inches in diameter.

(3) A set of three iron bars, one of Swedish charcoal iron, presented by Mr. Hadfield, and two specimens of English wrought iron bought for the purpose.

Complete analyses of these bars are given in Table I (Appendix).

The specimens were all cut from the same bar, except in the case of set (1), and the Swedish charcoal iron, of which five bars of each were supplied, and specimens taken indiscriminately from the bars.

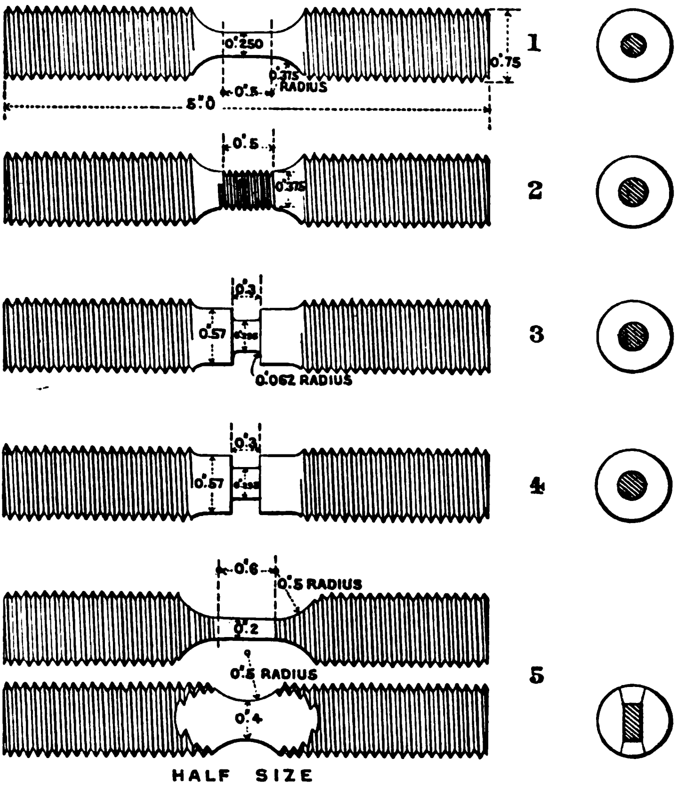
Complete tensile tests were made of each sample, the primitive limit of elasticity being carefully determined in each case. Several tests were made of each sample where possible, and, as might be expected, the results obtained from specimens cut from different parts of the same bar were often not in exact agreement, but no serious differences in tensile strength and elastic limits were observed. The results are given in Table II. The elastic limit was taken on a length of 8 inches by a Ewing extensometer, and the figures under the heading "primitive elastic limit" in the Table refer to the first noticeable deviation from proportionality in the extension. In the case of the moderately hard steels this limit is not so well defined as in the case of the soft steels and wrought irons.

Photomicrographs of sections taken from each sample are shown in Figs. 6–15, Plate 1. In the case of wrought iron No. 1 two distinct kinds of structure were observed in the same section, both of which are shown in Fig. 14.

Maximum Limits of Resistance of the Materials at 800 Reversals per Minute, and with a Ratio of Tension to Compression of 1·4.—These experiments were made with a crank-shaft having a throw of 2 inches, the connecting-rods being 12 inches in length, to give the above ratio of tension to compression. In selecting the form of specimen for giving the maximum resistance, it is evident that its length must be so short that there is no danger of buckling under compression, and

also that the changes of section must be very gradual. The form adopted is shown in *Figs.* 2, and is the same as that used in Messrs. Reynolds and Smith's experiments. The bars were turned out of the rough to ¾ inch in diameter, screw-cut the whole length to gauge, and finally turned down in the centre to the dimensions given, no grinding process being employed. The weight of the mass whose inertia pro-

Figs. 2.



FORMS OF TEST-PIECES USED.

duced the stresses in the specimens varied in these experiments from 29 to 52 lbs. This was made up partly of the cross-head and slippers with the tail-rod, and partly of turned cast-iron disks attached to the tail-rod, the number of which could be varied. This variation in weight was produced in steps of 1·7 lb., corresponding with a change in the range of stress in the specimen of 1·1 ton per square inch. As this variation is not greater than that found to

exist between the resistances of specimens cut from the same bar of steel, it was not considered necessary to make the increments in the range of stress smaller, except in some special cases in which this was done by a slight alteration in the diameter of the specimen. Specimens from all the ten kinds of material described above were tested until sufficient data had been obtained to enable the maximum resistance for fracture after one million reversals to be predicted with tolerable accuracy.

The numerical results are given in the Appendix, Table III. It will be noticed that a considerably greater number of tests have been made on some samples than on others. This has been partly accidental in some cases, the first ranges of stress imposed being in the neighbourhood of the real maximum, but in other cases it is due to the irregularity in the resistances of specimens cut from the same bar. This is especially noticeable in the case of the wrought iron No. 1, which is the least satisfactory of all the materials tested. This irregularity is also strongly marked in the micro-structure, which shows two characteristic forms of structure differing considerably from each other.

As is well known,[1] if a series of tests on any particular material are made at varying ranges of stress, and points are plotted whose ordinates are the ranges of stress and abscissæ the corresponding numbers of reversals for fracture, these points are found to lie approximately on a curve which is asymptotic to a horizontal line. The ordinate of this horizontal line may be taken to represent the range of stress corresponding to fracture after an infinite number of reversals.

The curves for the present experiments are shown in *Fig. 3*. From the results of some preliminary experiments it was found that it was not necessary to find points on these curves corresponding to fracture with more than one million reversals, since in all the materials used, the slope of the curve was practically zero when this limit had been reached. It may be pointed out that this was found to be the case also in the high-speed experiments of Messrs. Reynolds and Smith.[2] It was not the case in Wöhler's experiments, the slope of the curve at one million reversals being still considerable, especially in the case of the wrought-iron specimens. It will be seen from *Fig. 3* that in the present experiments the limiting range of stress is much more rapidly approached in the case of the harder materials than for the wrought irons and mild steels, which is also confirmed by Messrs.

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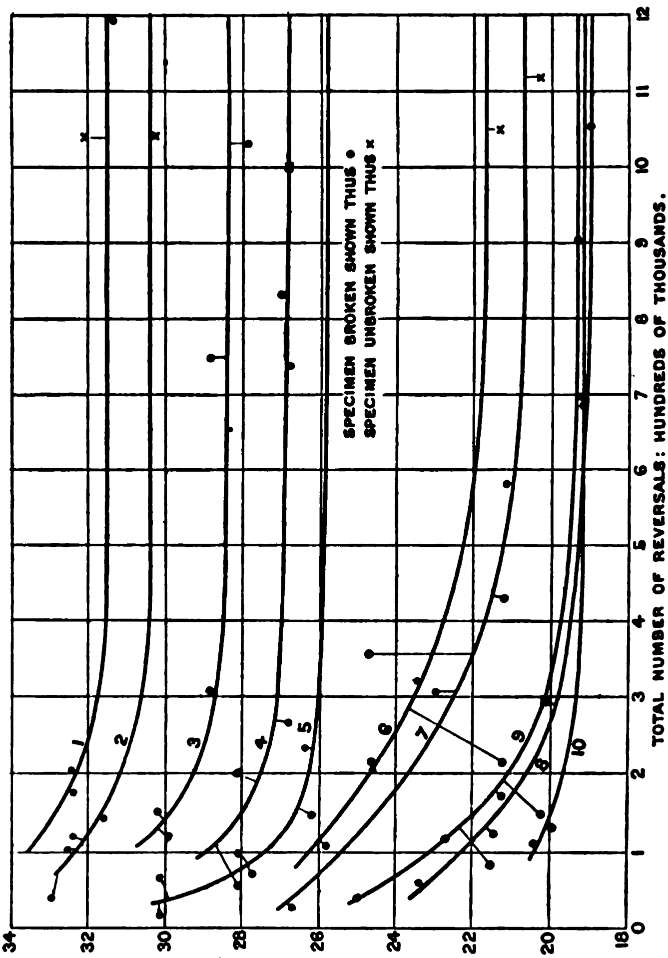
[1] Unwin, "The Testing of Materials of Construction," p. 351.

[2] Philosophical Transactions of the Royal Society, vol. cxcix, p. 294,

Reynolds and Smith's experiments. The values of the limiting resistances obtained from the curves are given in the Table on p. 89.

Effect of a Variation in the Ratio of Tension to Compression on the Limiting Range of Stress for Fracture after One Million Reversals.—Before making any comparison between the results of the present

Fig. 3.



1. Swedish Bessemer Steel, No. 3. 2. Swedish Bessemer Steel, No. 2. 3. Piston-Rod Steel. 4. Swedish Bessemer Steel, No. 1. 5. Mild Steel, No. 2. 6. Wrought Iron, No. 1. 7. Steel Forging. 8. Mild Steel, No. 1. 9. Wrought Iron, No. 2. 10. Swedish Iron.

Curves of Minimum Resistance to Reversals of Stress at 800 Reversals per Minute.

tests and those of previous experimenters, it was considered advisable to make the determination, previously referred to, of the truth of the common assumption that the resistance of materials subject to reversals of stress depends on the range of stress alone, and not on

MAXIMUM LIMITS OF RESISTANCE OF THE MATERIALS FOR ONE MILLION REVERSALS OF DIRECT STRESS AT A RATE OF 800 PER MINUTE AND WITH A RATIO OF TENSION TO COMPRESSION OF 1·4.

Materials.	Stress.		
	Tension.	Compression.	Range.
	Tons per Sq. In.	Tons per Sq. In.	Tons per Sq. In.
Swedish Bessemer steel, No. 3 .	18·37	13·12	31·5
„ „ „ No. 2 .	17·73	12·67	30·4
„ „ „ No. 1 .	15·63	11·16	26·8
„ charcoal iron	11·08	7·92	19·0
Piston-rod steel	16·51	11·79	28·3
Steel forging	12·01	8·59	20·6
Mild steel, No. 2	15·05	10·75	25·8
„ „ No. 1	11·02	7·88	18·9
Wrought iron, No. 2	11·19	8·01	19·2
„ „ No. 1	12·60	9·00	21·6

the actual limits of the stress. For this purpose a new crank-shaft, similar in all respects to the one previously used, except that the throw was ½ inch instead of 2 inches, was used with the same connecting-rods, and at the same speed as in the former trials. In this way the ratio of tension to compression was reduced from 1·40 to 1·09. In order to keep the dimensions of the specimens approximately the same, it was necessary to increase the reciprocating mass in the ratio 4 to 1, but as the bearing-surface of the slippers supporting these masses was large, and, as previously mentioned, under complete lubrication, it was not anticipated that the resistances at the surfaces would be appreciably increased.

For the purposes of the comparison, tests were made on specimens of the wrought iron No. 2, which was considered to be one of the most uniform of the materials tested, and which, owing to its low resistance, enabled the reciprocating mass to be made as small as possible. The results of the preliminary tests with the new arrangement were not satisfactory, the resistances being irregular, and indicating a limiting resistance considerably lower in amount than that determined in the first series of tests. It was at first thought that this was due to the wear of the guides of the slippers, so that new guides were made, and fitted with the greatest possible care. A series of tests, the results of which are stated in the Appendix, Table IV, gave somewhat improved results, but showed clearly that the limiting resistance was approximately 9 per cent. lower than in the first series with the large crank-shaft. The irregularity of the results of this second series of tests still left some suspicion that the

diminution in the resistance was not solely due to the change in the ratio of tension and compression.

As it seemed possible that the increased pressure on the slides due to the heavy reciprocating masses might affect the forces on the specimen, this was tested by accurately measuring the power required to drive the machine, both with the heavy masses attached and without them. It was found that with the heavy masses attached the power required was approximately 2 HP., and, although very sensitive instruments were used, no appreciable difference in the power was detected when the masses were removed, although the pressures on the slides were reduced in the ratio of 1 to 2·5, and the pressures on the crank-pins in the ratio of 1 to 1·5. As this test showed conclusively that the resistance of the mechanism was purely dependent on the speed, it was impossible to account for the reduced limits of resistance of the specimens by any resistance of the slippers.

There remained the possibility that this effect was due to a coincidence of the period of the machines with a period of vibration of the specimen. The best way of detecting this seemed to be by varying the dimensions of the specimens, and consequently the mass of the reciprocating pieces. For this purpose a third series of trials was made with smaller specimens and reciprocating masses not greatly in excess of those which were used in the first series with the large crank-shaft.

The results of these tests are given in Table V, and were considered satisfactory, there being no irregularities, so that the limiting values of the resistances could be accepted as reliable. It was considered advisable to determine the limit for another material besides the wrought iron No. 2, already alluded to, and for this purpose the Swedish iron was chosen.

The limiting values of the resistance of these two materials under the two sets of conditions are as follows:—

Material.	Limiting Range of Stress.	
	Ratio of Tension to Compression = 1·4.	Ratio of Tension to Compression = 1·09.
	Tons per Sq. Inch.	Tons per Sq. Inch.
Wrought iron, No. 2	19·20	19·40
Swedish iron	19·00	19·10

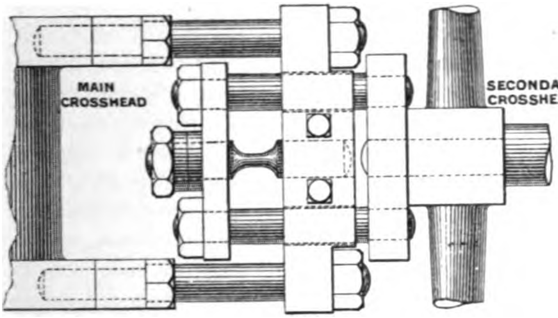
These values of the limiting resistance appear to justify the conclusion that this resistance is not affected by a change in the value

of the ratio of tension to compression of the above magnitude, and to indicate that the low resistances obtained with the large reciprocating masses were due to some secondary effect, probably a disturbance whose period coincided with one of the natural periods of vibration of the specimen. A somewhat similar case was observed and recorded by Messrs. Reynolds and Smith,[1] this, however, being a torsional effect.

The foregoing method of lowering the value of the ratio of tension to compression not being available for a further reduction, an attempt was made to obtain values of the resistance corresponding with still smaller ratios.

The device used for this purpose is shown in *Fig. 4*, and consists

Fig. 4.



of the adoption of an inverted shackle for holding the specimen, instead of the direct attachment hitherto used. In this way the specimen was subjected to compression at the beginning of the forward stroke and to tension at the end of the stroke. This shackle was used with both the small and the large crank-shafts, so that tests could be made on specimens in which the ratio of tension to compression was 0·92 and 0·72.

The results are given in the Appendix, Table VI. In the case of the wrought iron No. 2 at a ratio of tension to compression of 0·92, a resistance equal to the maximum value previously determined was obtained; and for the Swedish iron, with ratios of tension to compression of 0·92 and 0·72, the resistances were also approximately the same as in the case when the tension was the higher limit. It would therefore seem that the present experiments may be taken to

[1] Philosophical Transactions of the Royal Society, vol. cxcix, p. 289.

show that for the purposes of the designer a high value of the compression limit need not be taken as a case requiring special treatment.

General Case of the Maximum Resistance of the Materials.—From the experimental evidence obtained by varying the ratio of tension to compression between the values 1·4 and 0·72 there appears to be no doubt that between these limits and at the same rate of reversals, the variation in resistance of any material, as given by the maximum range of stress for fracture with one million reversals, is very small. Hence, for purposes of comparison with the other stress-coefficients of the material which are obtained by statical tests, half this range of stress may be conveniently taken as the maximum stress in tension or compression when subject to equal and opposite reversals of stress.

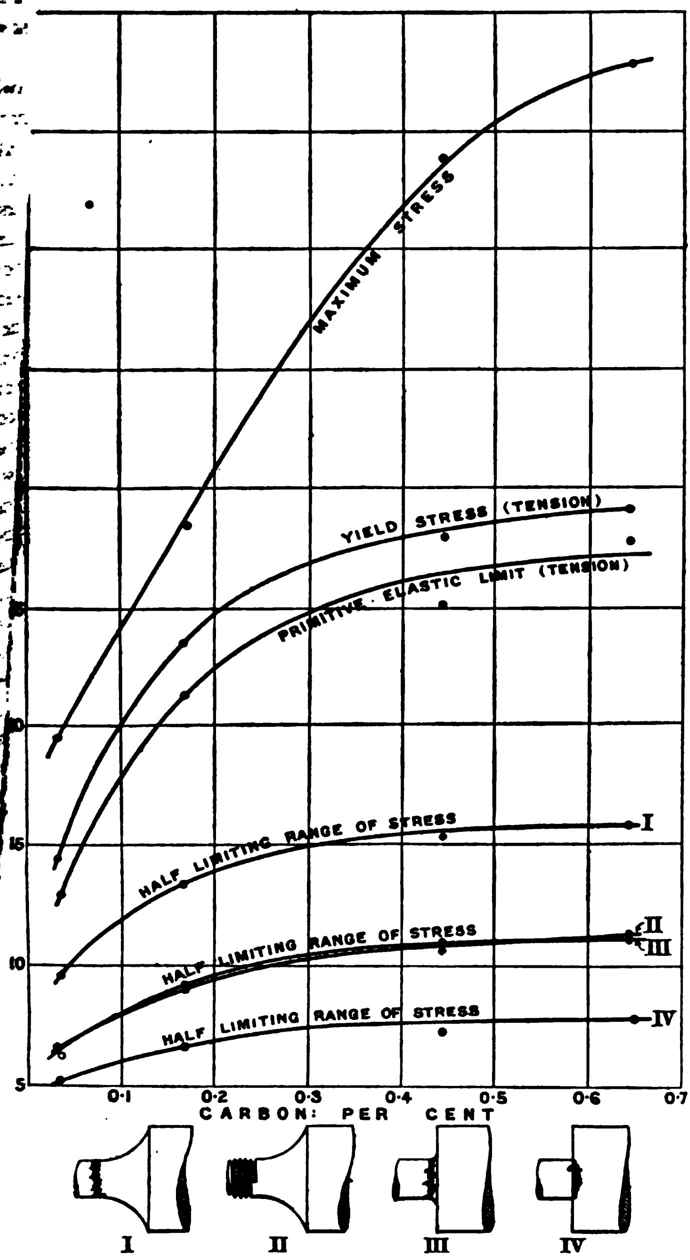
It is clear from the curves in *Fig. 3* that the resistance increases with the hardness and ultimate strength of the materials. The effect of the carbon content is best seen in the case of the four Swedish samples, which are the purest of the materials tested; although even here the comparison is inexact owing to the relatively large quantity of manganese in samples Nos. 2 and 3. Neglecting this variable factor the results for these bars (*i.e.*, half the maximum ranges of stress) have been plotted on a carbon base in *Fig. 5*, on which is also recorded the primitive elastic limits, the yield-points and the maximum stresses. From the regularity of the curves it would appear that the variation in the percentage of manganese present has not had any appreciable effect on the resistance of these four samples.

Comparisons between the resistances of the other materials used in the tests are difficult to make on account of both the considerable variation in amount of the chemical constituents other than carbon and manganese, and also of the different heat-treatment which the materials must have received. Thus the low resistance of the mild steel No. 1 may be due to the relatively large amount of phosphorus and silicon which it contains, and that of the specimens cut from the steel forging is probably due to the heat-treatment and slow cooling it went through. In some preliminary experiments which were made with a view to securing greater uniformity in the results, tests were carried out on specimens which had been raised to a temperature of 1,000° C. and then cooled slowly in air. It was found that by this treatment the resistance to reversals of stress was reduced to an amount varying from 75 to 85 per cent. of its value in the primitive condition. This is in agreement with the results of Mr. Rogers's experiments at Cambridge.[1]

The maximum ranges of stress obtained in the present experiments

[1] Journal of the Iron and Steel Institute, vol. lxvii (1905), p. 492.

Fig. 5.


MAXIMUM STRESS
YIELD STRESS (TENSION)
PRIMITIVE ELASTIC LIMIT (TENSION)
HALF LIMITING RANGE OF STRESS
I
HALF LIMITING RANGE OF STRESS
II
III
HALF LIMITING RANGE OF STRESS
IV
5
10
15
0·1
0·2
0·3
0·4
0·5
0·6
0·7
CARBON: PER CENT
I
II
III
IV

do not differ very widely from those of Wöhler[1] as far as it is possible to compare the materials used. Thus, for wrought iron the range of stress obtained by Wöhler was approximately 23·0 tons per square inch as against 19·3 in the present experiments; but it must be noted that in Wöhler's experiments the rate of change of stress with change of reversals was not nearly zero at that value, the material breaking with a range of 17·2 tons per square inch after 19 million reversals. To take another example, the range of stress obtained by Wöhler for specimens taken from Krupp cast-steel axles was 28·6 tons per square inch, as against the 28·4 tons per square inch range obtained in the present experiments for the piston-rod steel containing 0·44 per cent. of carbon.

The results obtained on Messrs. Reynolds and Smith's experiments differ widely from either of the above, apparently on account of the high rate of reversals. This will be seen from the following Table:—

Experimenter.	Wrought Iron.		Steel.	
	Reversals per Minute.	Maximum Range of Stress for 1 million Reversals.	Reversals per Minute.	Maximum Range of Stress for 1 million Reversals.
		Tons per Sq. Inch.		Tons per Sq. Inch.
Wöhler	60	23·0	60	28·6 (cast steel)
Reynolds and Smith .	1,890	11·7	1,892	11·9 (cast steel)
Authors	800	19·3	800	28·4 (steel of 0·44 per cent. of carbon)

Sir Benjamin Baker's results for soft and hard steels are also in fair agreement with those of Wöhler and those obtained in the present experiments. This agreement is remarkable when the totally different nature of the tests is taken into consideration.

Of the tests made by Mr. Rogers with the Wöhler method only those on the bars which were tested "as rolled" can be compared with the present experiments. The ranges of stress corresponding to fracture with one million reversals in Mr. Rogers's experiments on three steels, containing 0·27, 0·14 and 0·32 per cent. of carbon, were approximately 38, 32 and 32 tons per square inch respectively, all of which are considerably higher than the values obtained in the present experiments for steels of similar carbon content.

Relation between the Maximum Resistance and the Elastic Limit.—The value of the elastic limits given in Table II are taken from obser-

[1] Unwin, "The Testing of Materials of Construction," p. 347.

vations on the specimens in their primitive state, so that, according to Bauschinger's theory already alluded to, no general relation between the resistance to reversals of stress and the primitive elastic limits could be expected.

The following Table, which gives the values of the ratio of the maximum range of stress to the primitive elastic limits for all the materials experimented upon, tends to confirm this view:—

Material.	Ratio of Maximum Range of Stress to Primitive Elastic Limit.	Material.	Ratio of Maximum Range of Stress to Primitive Elastic Limit.
Swedish Bessemer steel—			
No. 3	1·13	Steel forging . . .	1·59
No. 2	1·21	Mild steel, No. 2 . .	1·80
No. 1	1·25	„ „ No. 1 . .	1·76
Swedish charcoal iron .	1·47	Wrought iron, No. 2 .	1·44
Piston-rod steel . . .	1·44	„ „ No. 1 .	1·51

Evidently according to this theory all these primitive elastic limits are due to overstrain in the production of the materials, because in no case does the ratio in the above Table approach the value 2.

It is worthy of notice that, with one exception, the value of the ratio is much higher in the case of the wrought irons and mild steels than for the harder steels. Further, it may be pointed out that when the specimen is cut from a comparatively large mass of material, as in the case of the steel forging and mild steel No. 2, the ratio has a high value, which is evidence in favour of Bauschinger's theory, since in these cases the hardening due to overstrain would most likely be less marked than on a bar of small diameter.

It appeared on further consideration that more conclusive evidence of the truth of this theory would be afforded in the following way:— If the maximum resistance of any material under reversals of stress is known, then, according to the theory, by subjecting a specimen of it to a small number of reversals of stress of intensity equal to or slightly exceeding this amount, the limits of elasticity tend to take up values which are called the "natural" elastic limits. From the theory, if the specimen is then subjected to a statical test in the ordinary way, either in tension or compression, its elastic limits in tension or compression should have values practically equal to the maximum tensile or compressive stresses which have been applied to it in the alternating-stress testing-machine.

For the purpose of verifying this the following specimens, which had undergone a fairly long test under reversals of stress, were used.

(A), A specimen of Swedish Bessemer steel, No. 3, which had undergone 1,561,000 reversals of stress of a range of 31·33 tons per square inch without fracture.

(B) and (C), Two specimens of Swedish Bessemer steel, No. 2, which had undergone 1,287,000 reversals of stress of a range of 29·10 tons per square inch without fracture.

A and B were tested in tension and C in compression.

As the length under observation was only ¾ inch it was necessary to employ a very sensitive extensometer for the purpose of measuring the strains. The Authors are indebted to Mr. John Morrow, M.Sc., of University College, Bristol, for kindly lending them one of his mirror extensometers, specially designed for short specimens, and which was admirably fitted for the work.

The results of the tests are given in the Table on p. 97, from which the approximate values of the elastic limit in each case can be estimated. Also, from the known ratio of tension to compression in these experiments, the maximum tensile stresses for specimens A and B and the maximum compressive stress for specimen C, which had been imposed in the alternating-stress testing-machine, can be calculated. Taking out these quantities the following comparisons can be made:—

	Tons per Square Inch.
Specimen A—	
Maximum tensile stress imposed in alternating-stress testing-machine	18·25
Approximate elastic limit in tension after test	17·30
Specimen B—	
Maximum tensile stress imposed in alternating-stress testing-machine	16·90
Approximate elastic limit in tension after test	16·40
Specimen C—	
Maximum compressive stress imposed in alternating-stress testing-machine	12·10
Approximate elastic limit in compression after test	12·60

Taking into consideration the fact that the values of the primitive elastic limits in tension of these materials were 27·66 tons per square inch for the sample A, and 25 tons per square inch for samples B and C, the comparisons of stresses made above are strong evidence in favour of the theory that the primitive elastic limits of iron and steel are frequently artificial and unstable under reversals of stress.

Limits of Resistance of the Materials when in certain forms commonly occurring in machine details, but which are not of

Load in Lbs.	Tensile Tests.				Compression Test.	
	Specimen A. Diameter 0·25 In.		Specimen B. Diameter 0·25 In.		Specimen C. Diameter 0·25 In.	
	Extensometer Reading.	Differences.	Extensometer Reading.	Differences.	Extensometer Reading.	Differences.
200	1,039		1,055		..	
		43		38		..
400	1,132		1,093		..	
		44		42		..
600	1,176		1,135		866	
		43		40		42
800	1,219		1,175		824	
		42		40		43
1,000	1,261		1,215		781	
		43		41		43
1,200	1,304		1,256		738	
		43		41		44
1,400	1,347		1,297		694	
		43		42		46
1,600	1,390		1,339		648	
		44		43		47
1,800	1,434		1,382		601	
		46		47		..
2,000	1,480		1,429		..	
		47		..		..
2,200	1,527		..		..	

maximum resistance.—As it was not possible to undertake the determination of the resistance of a large number of these forms, the following three were chosen as being the most important cases occurring in machine practice.

(1) Specimens on which a screw-thread had been cut.

(2) Specimens having a moderately rapid change of section.

(3) Specimens having a sudden change of section.

The three types of specimens are shown in *Figs.* 2. In the case of the screwed specimens the material was turned down to $\frac{3}{8}$ inch in diameter and a Whitworth V thread was cut on it. In the other specimens the change of dimensions was from a diameter of 0·50 inch to a diameter of 0·295 inch, the corner being left perfectly square in set (3), and having a fillet of 0·062-inch radius in set (2).

The experiments on these specimens were made under conditions precisely similar to those under which the determination of the maximum resistance was made, *i.e.*, with a ratio of tension to compression of 1·4, and at a speed of 800 reversals per minute; so that a reliable comparison can be made between the resistance of these forms and that of the maximum resistance in the same material. Owing to the difficulty of producing exactly similarly machined

specimens of these forms, it was hardly expected that the results woul be so definite as in the case of the maximum resistances, but by payin careful attention to the machining these difficulties were overcome.

The results of the experiments are given in the Appendix, Table VII, VIII and IX, from which the limiting ranges of stress fc fracture after one million reversals have been deduced. Thes limiting ranges are given in the following Table, together with th ratio of this limiting range to the maximum range in each case The chief features of interest are—

(1) That the resistances of all these forms are, in every case, fa below the corresponding maximum resistances of the materials.

(2) That the resistances of forms Nos. 1 and 2 are practically th same for any given material, and that the ratio of these resistance to the corresponding maximum resistances does not vary greatly fo the different materials.

(3) That in the case of the specimens having a sudden change c section, the percentage of maximum strength appears to depend or the hardness of the steel, being approximately 48 per cent. for th hard steels, and 55 to 65 per cent. for the wrought irons and mild steels. It is, however, worthy of notice that, even under th circumstances supposed to be most fatal to hard steels, *i.e.* a sudden change of section, these steels are very appreciably stronger than wrought irons and mild steels.

Limits of Resistance of the Materials when in other Forms than tha giving the Maximum Resistance, at a Rate of 800 Reversals pe Minute and a Ratio of Tension to Compression of 1·4.

Material.	Specimen Screw-Cut with a V Thread.		Specimen having Moderately Rapid Change of Section.		Specimen having Sudden Change of Section.	
	Limiting Range of Stress.	Ratio of Limiting Range to Maximum Range.	Limiting Range of Stress.	Ratio of Limiting Range to Maximum Range.	Limiting Range of Stress.	Ratio of Limiting Range to Maximum Range.
Swedish Bessemer steel—	Tons per Sq. Inch.		Tons per Sq. Inch.		Tons per Sq. Inch.	
No. 3	21·9	0·69	21·6	0·68	15·3	0·48
No. 2	21·3	0·70	21·8	0·72	14·4	0·47
No. 1	18·0	0·67	18·3	0·68	13·0	0·48
Swedish charcoal iron .	13·0	0·68	12·3	0·65	10·3	0·54
Piston-rod steel . . .	18·6	0·66	20·0	0·71	16·9	0·60
Mild steel, No. 2 . .	18·4	0·71	18·5	0·72	14·1	0·55
Mild steel, No. 1 . .	13·8	0·74	13·6	0·72	12·2	0·64
Wrought iron, No. 1 .	16·7	0·77	17·5	0·81	12·9	0·60

The results for the Swedish materials are also shown, plotted on a carbon base, in the curves of *Fig. 5*, to enable a comparison between these and the other stress-coefficients of the materials to be made.

Microscopical Investigation of the Changes taking place in the Crystalline Structure of the Materials during the reversals of stress-test, and the manner in which ultimate failure occurred.—The changes which take place in the crystalline structure of metals subjected to permanent strain have been studied by Messrs. Ewing and Rosenhain,[1] who discovered that the strain takes place by the development of slipping planes in the body of the crystalline grains of which the material is composed, the traces of these planes showing on the polished surface of the metal as a series of parallel lines having a definite direction for each grain. These lines have been called "slip-lines," and it was found that two or more sets of these slip-lines, inclined to each other, may exist in the same crystalline grain. This method has been applied to the case of the fatigue of iron by Messrs. Ewing and Humfrey,[2] who have made periodic microscopical examinations of the polished and etched surface of iron subject to the Wöhler test during the progress of the test. It was then found that when the stress on the specimen was that which would ultimately cause failure after a considerable number of reversals, slip-lines appeared on certain crystals at an early stage in the test. As the test proceeded, these lines broadened out, while others appeared in crystals which had been previously intact. At a later stage in the test these broad bands became massed together, forming a wider band with ill-defined edges, and this eventually developed into a crack in the specimen, complete failure taking place by the joining up of several of these cracks.

As far as the Authors are aware, this method of investigation has not been used for materials subject to direct tension and compression, or in the case of the fatigue of steels having a moderately high percentage of carbon, so that there appeared to be good reasons for further work in this direction.

For the present experiments the surface under observation was in the early trials obtained by making a very narrow flat on the round specimen parallel to its axis. This surface was polished and etched in the usual manner and the specimen was placed in the testing-machine, being taken out at regular intervals for microscopical examination.

The first experiments were made on specimens of Swedish iron, and

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[1] "The Crystalline Structure of Metals" (*Bakerian Lecture*). Philosophical Transactions of the Royal Society, vol. cxciii, p. 353.

[2] *Ibid*, vol. cc, p. 241.

the same phenomena were observed as those discovered by Messrs. Ewing and Humfrey, the slip-lines gradually appearing, broadening out, and then becoming massed together and developing into a crack. It was further noticed, however, that, in many cases, the first set, or sets, of slip-lines observed were not those along which ultimate fracture occurred, or which developed into cracks. It was quite common to find a set of slip-lines in the early stages of a test which apparently ceased to broaden out or extend appreciably as the test proceeded. An example of this is shown in Figs. 31 and 32, Plate 2, in which the slip-lines developed after 150,000 reversals show very little alteration after an additional 614,000 reversals. This is possibly due to an initially unequal distribution of stress in the crystalline structure, which is corrected by slight slipping in certain crystals, the effect being an increased resistance of the section of the specimen at that point.

Owing to this peculiarity it was found that, out of ten or twenty perfectly definite groups of slip-lines which were developed on the surface of the specimen, it was impossible to detect, until fairly near the end of the test, which group of slip-lines would develop into the crack which caused the fracture of the specimen. It was therefore found necessary to devise a form of specimen in which the position of the line of fracture could be kept within fairly narrow limits, taking care at the same time that this position was not made so definite as to influence the direction of the line of fracture. The form of specimen adopted is shown in *Fig. 2*, No. 5.

The photomicrographs in Figs. 16–22, Plate 1, furnish an example of the gradual development of slip-lines into a crack, during the test of a specimen of Swedish charcoal iron. This material had been previously heated to 1,000° C., and cooled slowly in air in order to make the structure more uniform and the crystalline grains larger in size. Fig. 16 shows the system of slip-lines developed near the edge of the specimen after 25,000 reversals. In Fig. 17, taken after an additional 146,000 reversals, the lines are seen to have become more numerous, and in the boundary crystal a secondary set of slip-lines have appeared, and a short dark band has formed, indicating the commencement of the crack. In Fig. 18, after 50,000 more reversals, another crack is seen forming round the sides of the boundary of one of the inner crystals. In Fig. 19 this crack has spread farther, and it will be noticed that the crack developed in the boundary crystal has now taken a direction approximately at right angles to the primitive slip-lines in that crystal. After 306,000 reversals the specimen was repolished and re-etched in order to make the path of the crack clear. This is

shown in Fig. 21. As there appeared to be some doubt if all the lines in this photograph were really cracks, the specimen was again re-polished and re-etched, the section being shown in Fig. 22. The amount of material removed from the surface during this last process will be evident from the considerable increase in size of the small crystal in the left centre of the photograph, so that the lines in the photograph appear to be the traces of actual cracks in the crystals. The two cracks previously detected are seen to have joined up and to have proceeded into the adjoining crystals.

The photomicrographs in Figs. 23–26, Plate 1, show the development of a crack at the bottom of a screw-thread. In this test a specimen of Swedish iron was turned to a diameter of 0·75 inch and a V screw of ten threads to the inch cut on it. The centre part of the specimen was then milled flat so as to present a section of the screw, which was then polished and etched in the usual manner.

Fig. 23 shows the state, after 60,000 reversals, of a crack which has begun at the bottom of the thread. In the bottom left-hand corner is seen another case of the crack proceeding at right angles to the primitive slip-lines. The section at this stage is shown on a smaller scale in Fig. 24. Fig. 25 shows a further development after an additional 10,000 reversals. The last photograph before fracture is Fig. 26, in which is seen the double system of slip-lines developed in the crystal on the right-hand side. It will be noticed that in Fig. 25 this crystal is perfectly intact.

The photomicrographs in Figs. 27–30, Plate 2, show the path of a crack which has developed at the sudden change of section in a specimen of Swedish iron of rectangular section, one of the polished sides of which is shown in the photographs. The chief point of interest here is the unstrained condition of the crystals in the neighbourhood of the crack, indicating the great source of weakness at the change of section.

The microscopical investigation of the manner of failure of specimens of moderately hard steels is of the greatest engineering importance, as the relative behaviour of the different constituents under reversals of stress does not appear to be well known. The reason that these steels have not received so much attention as the purer irons seems to be the extreme difficulty of detecting systems of slip-lines in the ferritic or in the pearlitic areas in the sections of moderately high-carbon steels. On this account microscopical examination has generally been confined to the study of fully developed cracks or actual fractures in the materials. In a Paper on "Impact Tests on the Wrought Steels of Commerce" Messrs.

A. E. Seaton, M. Inst. C.E., and A. Jude[1] show photographs of the fracture line in hard steels under impact, and from the invariable tendency of the line of fracture to pass through the ferritic areas, have arrived at the conclusion that ferrite is the weak constituent of the steels and the cause of the ultimate failure.

As it was important to discover if the fracture of hard steels under reversals of stress was caused by the development of cracks in the ferritic areas, the Authors made a number of experiments on the highest carbon steels of the series tested, although it may be pointed out that in these experiments since the stress was uniform across the section, any sectional weakness due to the preponderance of ferritic material would not necessarily show itself as a crack passing through the ferrite on the surface.

As will be seen from the micro-photographs of the sections in Figs. 6–15, Plate 1, the high-carbon materials were not in a very suitable condition for the test, owing to the boundaries between the pearlitic and ferritic constituents not being well defined. It was found that by raising the bars to 1,000° C. and cooling slowly in air, much better conditions for microscopical observation were obtained, as will be seen from the photographs in Figs. 33–36, Plate 2. Of these Figs. 33 and 34 show different portions of the surface of a specimen containing 0·64 per cent. of carbon after 20,000 reversals.

It will be seen that the small cracks which are being developed in different parts of the surface pass through the narrow bands of ferrite which surround the masses of pearlite.

Fig. 35 shows a portion of the surface of the same specimen after the crack had proceeded for some distance into the specimen. At this stage the path of the crack was so indistinct that repolishing was necessary. Here also the tendency of the crack to pass through ferrite will be noticed.

Fig. 36 shows the path of a crack developed in a specimen of steel containing 0·44 per cent. of carbon after 295,000 reversals. This case is not such a good one as the previous test for showing the selective path of the crack, owing to the relatively larger amount of ferrite present.

General Conclusions.—The general conclusions which may be drawn from the experiments described in this Paper may be stated as follows:—

(1) As far as comparisons can be made between these experiments on direct stress and those of previous experimenters on transverse stress, there appears to be no marked falling-off in the resistance of

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[1] Proceedings of the Institution of Mechanical Engineers, 1904, p. 1135.

iron and steel due to increasing the rate of reversals from 60 to 800 per minute.

(2) The superiority in resistance to reversals of stress of moderately high-carbon steels over low-carbon steels and wrought irons which was discovered by Wöhler at a low rate of reversals is still maintained up to a rate of 800 per minute, although according to the experiments of Messrs. Reynolds and Smith this superiority no longer exists where the rate is in the neighbourhood of 2,000 per minute.

(3) The resistance of iron and steel to reversals of stress, when in certain forms commonly occurring in machine details, bears a definite ratio to the maximum resistance of the same material, the value of the ratio appearing to depend on the rapidity of the change of section.

(4) The maximum resistance of a sample of iron or steel is defined by the maximum range of stress to which it can be subjected without fracture, and is independent, within fairly wide limits, of the actual numerical value of the maximum stress.

(5) The microscopical study of the changes which occur in the structure of the materials during reversals of direct stress shows that these changes are of the same nature as those which previous experimenters have observed in the case of iron under transverse stresses. In the case of moderately high-carbon steels, strong evidence has been discovered that the lines of weakness pass through the regions of ferrite, which is in agreement with the observations of other experimenters in cases of impact.

Finally, as regards the dependence of the resistance to reversals upon what may be termed the statical stress constants of materials, although the Authors recognize that much more work should be done before any definite relation can be stated, they are of opinion that the experiments on the range of the elastic limits here described afford strong confirmation of the theory of Bauschinger which has been discussed in the early part of the Paper.

The Authors beg to thank Dr. R. T. Glazebrook, Assoc. Inst. C.E., Director of the Laboratory, for the interest which he has taken in the work, and the facilities which he has given for carrying out the experiments.

The Paper is accompanied by five drawings and thirty-one photographs, from which Plates 1 and 2 and the Figures in the text have been prepared.

[APPENDIX.

APPENDIX.

TABLE I.—ANALYSES OF MATERIALS USED.

—	Carbon.	Manganese.	Silicon.	Sulphur.	Phosphorus.
Swedish Bessemer steel, No. 3	0·645	0·260	0·062	0·010	0·028
,, ,, ,, No. 2	0·446	0·370	0·058	0·012	0·028
,, ,, ,, No. 1	0·170	0·100	0·021	0·012	0·013
Swedish charcoal iron . . .	0·039	trace	trace	0·00	0·018
Piston-rod steel	0·446	0·470	0·063	0·044	0·067
Steel forging	0·336	0·560	0·072	0·021	0·026
Mild steel, No. 2	0·381	0·680	0·086	0·056	0·066
,, ,, No. 1	0·065	0·040	0·148	0·010	0·135
Wrought iron, No. 2 . . .	0·195	0·005	0·086	0·011	0·054
,, ,, No. 1 . . .	0·029	0·070	0·127	0·024	0·219

TABLE II.—TENSILE TESTS OF MATERIALS USED.

—	Primitive Elastic Limit.	Yield Point.	Maximum Load.	Total Elongation on 8 Inches.
	Tons per Square Inch.	Tons per Square Inch.	Tons per Square Inch.	Percentage.
Swedish Bessemer steel, No. 3	27·66	29·10	47·60	12·9
,, ,, ,, No. 2	25·00	28·05	43·75	17·0
,, ,, ,, No. 1	21·42	23·78	28·53	22·8
Swedish charcoal iron . . .	12·93	14·46	19·60	33·8
Piston-rod steel	19·62	22·32	43·85	18·1
Steel forging	12·94	14·52	29·47	16·6
Mild steel, No. 2	14·30	15·82	28·30	24·6
,, ,, No. 1	10·72	13·43	21·92	28·0
Wrought iron, No. 2 . . .	13·37	14·67	25·58	23·8
,, ,, No. 1 . . .	14·28	16·47	23·76	27·0

TABLE III.—RESULTS OF EXPERIMENTS TO DETERMINE THE MAXIMUM RESISTANCE OF THE MATERIALS.

Ratio of tension to compression = 1·4.

Material.	Mean Reversals per Minute.	Range of Stress.	Total Reversals up to Fracture.
	No.	Tons per Square Inch.	No.
Swedish Bessemer steel, No. 3	796	32·43	179,000
	797	32·49	204,000
	797	32·05	1,036,600 [1]
	795	31·37	1,194,500 [1]
	795	31·33	1,561,000 [1]
Swedish Bessemer steel, No. 2	800	33·00	41,000
	797	32·59	103,000
	796	32·43	124,000
	799	31·68	138,000
	797	30·25	1,036,600 [1]
	796	30·17	129,500
	797	29·75	1,036,600 [1]
	796	29·10	1,287,000 [1]
	796	29·10	1,287,000 [1]
Swedish Bessemer steel, No. 1	800	28·16	199,500
	796	28·06	57,200
	798	26·94	830,900
	796	26·80	270,500
	796	26·80	738,700
	796	26·80	1,001,000
	795	25·65	2,148,000 [1]
	795	25·65	2,148,000 [1]
Swedish charcoal iron . . .	780	20·42	111,500
	795	20·00	123,800
	793	20·00	135,800
	796	19·45	556,200
	795	19·15	693,500
	794	18·10	1,010,800 [1]
	792	18·47	1,360,000 [1]
Piston-rod steel	796	30·16	154,800
	793	29·93	120,100
	794	28·85	308,300
	793	28·80	752,000
	796	27·88	1,032,000 [1]
	796	27·88	3,409,000 [1]

[1] Not broken

TABLE III.—*continued.*

Material.	Mean Reversals per Minute.	Range of Stress.	Total Reversals up to Fracture.
	No.	Tons per Square Inch.	No.
Steel forging	799	26·72	25,700
	799	24·75	356,100
	788	23·02	307,300
	795	21·20	432,000
	793	21·10	386,300
	797	20·20	1,116,300[1]
	794	19·09	1,782,800[1]
Mild steel, No. 2	797	30·17	14,500
	797	30·17	68,000
	799	28·06	97,800
	794	27·77	72,900
	789	26·40	236,000
	787	26·20	150,100
	797	25·78	1,914,000
	796	25·71	1,330,000
	794	23·29	2,000,000[1]
Mild steel, No. 1	794	23·37	58,000
	793	23·32	139,000
	799	21·42	123,000
	795	21·20	418,300
	796	20·15	298,000
	796	20·15	605,200
	791	18·95	1,055,300
Wrought iron, No. 1 . . .	795	27·86	100,800
	793	27·73	130,500
	797	26·86	302,000
	794	26·66	200,000
	795	25·80	107,400
	795	25·80	253,000
	792	24·60	204,000
	792	24·60	217,300
	795	23·43	373,400
	795	21·25	1,000,000[1]
	796	21·24	214,900
	797	20·20	1,116,300[1]
	793	19·05	1,028,700[1]
	793	19·05	1,028,700[1]
Wrought iron, No. 2 . . .	799	25·03	38,900
	803	22·70	117,100
	802	21·57	85,400
	800	21·28	174,000
	793	20·22	150,000
	796	20·16	296,000
	798	19·30	904,800

[1] Not broken.

TABLE IV.—DETERMINATION OF MAXIMUM RESISTANCE.

Ratio of tension to compression, 1·09. Throw of crank = 0·5 inch.
Weight of reciprocating mass, 110 lbs.

Material.	Mean Reversals per Minute.	Range of Stress.	Total Reversals up to Fracture.
	No.	Tons per Square Inch.	No.
Wrought iron, No. 2	800	20·94	92,500
	792	19·66	356,500
	799	19·20	582,800
	797	18·60	473,000
	795	18·51	192,000
	793	17·79	942,000

TABLE V.—DETERMINATION OF MAXIMUM RESISTANCE.

Ratio of tension to compression, 1·09. Throw of crank = 0·5 inch.
Weight of reciprocating masses, 45–47 lbs.

Material.	Mean Reversals per Minute.	Range of Stress.	Total Reversals up to Fracture.
	No.	Tons per Square Inch.	No.
Swedish iron . . .	819	19·88	271,800
	818	18·90	1,345,000[1]
	819	18·35	1,112,000[1]
Wrought iron, No. 2	825	22·10	171,200[1]
	818	19·35	1,045,000[1]

TABLE VI.—DETERMINATION OF MAXIMUM RESISTANCE WITH HIGH COMPRESSION LIMIT.

Approximate reversals = 800 per minute. Throw of crank = 2·0 inches.
Weight of reciprocating masses 32–35 lbs.

Material.	Ratio of Tension to Compression.	Range of Stress.	Total Reversals up to Fracture.
		Tons per Square Inch.	No.
Swedish iron . . .	0·92	20·10	81,000
	0·92	18·90	486,600
	0·92	17·65	1,029,800[1]
	0·72	18·38	523,500
	0·72	18·47	1,478,000[1]
	0·72	17·58	1,004,000[1]
Wrought iron, No. 2	0·92	19·35	1,045,000[1]

[1] Not broken.

TABLE VII.—RESULTS OF EXPERIMENTS ON THE RESISTANCE OF THE MATERIALS WHEN IN THE FORM OF SCREWED SPECIMENS (*Fig. 2*).

Ratio of tension to compression = 1·4.

Dimensions of screw ⅜ inch Whitworth thread.

Material.	Mean Reversals per Minute.	Range of Stress.	Total Reversals up to Fracture.
	No.	Tons per Sq. Inch.	No.
Swedish Bessemer, No. 3	795	23·60	107,100
	795	23·30	107,600
	797	21·72	1,112,700[1]
Swedish Bessemer, No. 2	796	22·60	90,700
	796	21·62	648,000
Swedish Bessemer, No. 1	795	21·60	92,100
	793	21·50	75,900
	794	20·76	102,300
	800	19·45	427,000
	797	18·48	487,600
Swedish iron	796	13·77	279,900
	794	12·96	1,083,200[1]
Piston-rod steel . . .	793	20·71	312,100
	797	20·23	181,500
	793	18·60	928,000
Mild steel, No. 2 . .	795	18·48	555,000
	795	18·48	865,000
Mild steel, No. 1 . .	795	16·93	234,000
	797	15·30	368,200
	793	14·40	308,700
	793	13·73	1,065,700[1]
Wrought iron, No. 1 .	800	19·30	370,400
	800	18·50	12,500
	793	18·36	183,000
	799	17·78	349,900
	792	16·78	691,900

[1] Not broken.

TABLE VIII.—RESULTS OF EXPERIMENTS ON THE RESISTANCE OF THE MATERIALS WHEN IN THE FORM OF SPECIMENS HAVING A MODERATELY RAPID CHANGE OF SECTION (*Fig. 2*).

Ratio of tension to compression 1·4.

Material.	Mean Reversals per Minute.	Range of Stress.	Total Reversals up to Fracture.
	No.	Tons per Sq. Inch.	No.
Swedish Bessemer, No. 3	794	22·50	403,500
	795	21·75	315,000
	795	21·60	1,000,000[1]
Swedish Bessemer, No. 2	795	22·55	797,300
	793	21·60	1,129,000[1]
Swedish Bessemer, No. 1	797	20·10	322,200
	798	19·33	371,300
	796	18·46	822,200
Swedish iron	796	13·75	340,600
	793	13·72	244,700
	793	12·93	562,100
	796	12·30	995,500
Piston-rod steel . . .	790	21·52	135,400
	797	20·10	746,200
Mild steel, No. 2 . .	796	20·05	334,800
	797	19·28	338,700
	797	18·55	912,300
Mild steel No. 1 . .	794	16·80	160,800
	793	14·40	428,900
	795	13·76	594,700
Wrought iron, No. 1 .	800	20·20	349,000
	799	19·38	126,600
	799	18·63	229,700
	794	17·57	871,900

[1] Not broken.

TABLE IX.—RESULTS OF EXPERIMENTS ON THE RESISTANCE OF THE MATERIALS WHEN IN THE FORM OF SPECIMENS HAVING A SUDDEN CHANGE OF SECTION (*Fig. 2*).

Ratio of tension to compression = 1·4.

Material.	Mean Reversals per Minute.	Range of Stress.	Total Reversals up to Fracture.
	No.	Tons per Sq. Inch.	No.
Swedish Bessemer, No. 3	790	18·30	96,900
	801	17·10	124,200
	796	15·27	1,356,000[1]
Swedish Bessemer, No. 2	793	21·50	118,500
	801	19·50	88,600
	799	17·00	158,000
	795	15·25	299,400
	793	14·40	951,700
Swedish Bessemer, No. 1	795	15·23	207,600
	793	13·73	397,700
	794	12·95	201,800
	794	12·94	1,007,000[1]
Swedish iron	789	12·02	184,000
	794	11·54	263,700
	793	10·90	314,400
	795	10·36	712,300
Piston-rod steel . . .	799	17·78	131,000
	797	16·96	712,300
Mild steel, No. 2 . . .	796	16·87	98,000
	796	15·26	322,800
	793	14·40	529,300
Mild steel, No. 1 . . .	792	13·71	157,800
	792	12·17	1,122,700[1]
Wrought iron, No. 1. .	798	20·16	94,000
	791	13·70	296,800
	795	12·96	854,200

[1] Not broken.

[DISCUSSION.

Discussion.

The PRESIDENT moved a vote of thanks to the Authors for their valuable Paper. The President.

Mr. F. E. ROBERTSON thought it would have been helpful to the reader if the substances had been classified in the Paper, all the irons being put together, and the steels following in the order of their ultimate strength. Another matter of mere wording was perhaps of more importance. Cast-steel axles were spoken of. Cast steel was used by engineers only to signify material that had been run to its ultimate state in the mould. A wheel-centre would be described as cast steel, but not an axle; for although the latter was certainly cast in the form of an ingot, the subsequent forging altered it. Incidentally, he might say that experiments on the resistance of cast steel would be very welcome. He had been unable to reconcile the statement on p. 92—"It is clear from the curves in *Fig. 3* that the resistance increases with the hardness and ultimate strength of the materials"—with the figures given, and therefore he had plotted a diagram (*Fig. 37*) in order to arrive at an understanding of the matter. The samples were arranged in the order of their ultimate strength. The slanting line at the top was the curve of ultimate strength from the highest to the lowest; the dotted line showed the maximum range of stress; the lowest line showed the yield-point. He chose that rather than the elastic limit because it was what was obtained in commercial testing; but the elastic-limit curve would be just below it and parallel to it. From that diagram it seemed to him that the range had really very little reference to the ultimate strength, but followed exactly the yield-point. There were also one or two interesting points brought out in the diagram, one being the beneficial result of pure material. Nos. III and IV showed that the yield-point and the ultimate range were remarkably near the maximum tensile strength. Those were particularly pure materials, Swedish Bessemer steel and Swedish iron. No. X showed a better result in practice than No. IX, which was wrought iron a good deal stronger than No. X. No. VIII was inferior mild steel, a steel that would have been condemned by anyone on the analysis; the phosphorus was far too high and the manganese was so low that the steel must have been rotten. He thought there must be a misprint, and that the manganese was 0·4 per cent., not 0·04 per cent. At all events, that would account for the poor results of that steel. Mr. Robertson.

Mr. Robertson. With reference to the annealed pieces, which were said to have been heated to a temperature of 1,000° C., it would be interesting to know the percentage of carbon in that steel, because the effects of heat-treatment on the steel depended very much on the carbon content. At any rate, 1,000° was rather a high temperature at which to anneal it. It would be interesting also to know how the ultimate strength and the elastic limit were affected—whether they were reduced as well as the range. With reference to the figures given on p. 96 with regard to the range above and below zero from tension to compression, a simple tension-test for the elastic limit would really never be trusted. It was his practice to check such tests with an occasional compression-test, and if the two were the same, the material might be assumed to be tolerably well in a state of rest. But, as the Paper showed, the sum of the two gave the real range of stress that the material would stand. It had been always his idea that the elastic limit was really the thing that, for the engineer's purpose, settled the value of the material. In that connection a comparison should be made between No. VI and No. III. No. VI had a higher ultimate strength, but it was nowhere near No. III either in the yield-point or in the available strength. No. VI could also be compared with No. IV. No. VI was a steel forging and No. IV was a piece of very soft charcoal iron. No. VI had 10 tons more apparent strength than No. IV, but it was no better in the yield-point, and only about

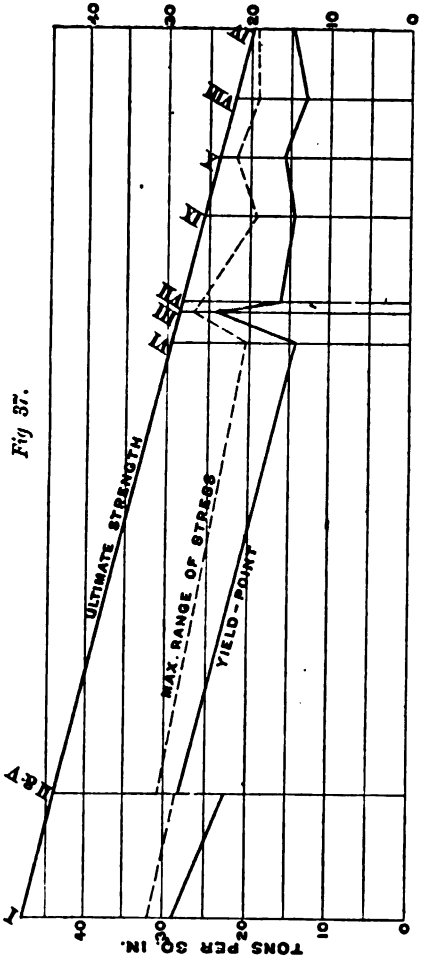

Fig 37.

1 ton better in its effective service. That showed the very erroneous deductions that might be arrived at by merely regarding the ultimate strength of a material. He did not see why it would not suffice to specify simply the minimum yield-point and the minimum elongation for steel, because those were the properties with which the engineer really had to deal. The experiments in the Paper were very interesting as far as they went, and created a thirst for more information. A good deal had been done to ascertain the effects of heat-treatment on the ultimate strength and the elastic limit of various steels, and if further experiments were conducted to give the relation of the effective strength, the range of stress, and other qualities, some very valuable information would be afforded. His own impression was that they would be found, as in *Fig. 37*, always to follow the elastic limit and not the ultimate strength. Mr. Robertson.

Professor W. C. Unwin observed that the Paper was really one of great importance, because all rational designing must be based on the determination of the question with which it dealt. The investigation, as the Authors claimed, was important, because it dealt with much more modern materials than those used in the wonderful research made by Wöhler soon after 1850. The Authors might, however, have given a little credit to Bauschinger, who had made experiments of that kind on materials of a much more modern character. Apart from its general interest, the Paper was valuable as establishing two points. Previous experiments had been made on variation of stress in material in tension, in torsion, and by two different methods of bending. No previous experiments had been made in which there was a simple reversal of direct stress. The means of doing this had been inquired for, but not found until Professor Osborne Reynolds invented the machine used in the present tests. The important point which came out, he thought, was—speaking broadly, and so far as it was possible to compare the materials used by the Authors with those used previously—that the new experiments entirely confirmed the old ones; the range of stress within which the material was safe turned out to be much the same in the present experiments as in the experiments made by four other different methods, and that, for many reasons, was a very important result. Another point was that for a very considerable variation of the speed of variation of stress—the number of repetitions of stress per minute—it did not appear that the rate of variation had much influence on the results. Those two results were of considerable importance, and were both new. One considerable achievement of Professor Osborne Reynolds's machine used at the National Physical Laboratory was, that a test Prof. Unwin.

Prof. Unwin. of what might be called the fatigue of material could be made in a much shorter time than before. He had carried out a number of experiments, and had had bars running for 12 months or more before they broke down, which caused the test to be exceedingly tedious. In his case he could not work with more than 150 changes of stress per minute, whereas the Authors had obtained 800 per minute, which shortened the period very much. He desired rather strongly to insist on a defect in the Paper. It was expected of the National Physical Laboratory that a research would be carried out in all its branches, and although the investigation had been carried out in some directions more completely than in any previous research, it would have been exceedingly interesting if, simultaneously, some experiments had been made with the same materials under simple variation of tensile stress, that was, stress varying between zero and a maximum tension. For certain cases, such as those of piston-rods, it was important to know the safe range of stress when there was complete reversal; but there were far more numerous cases in designing machines and structures where there was no complete reversal of stress, but only a variation of stress. Apart from that, it was known that Wöhler's old experiments plotted very simply, and, so far as experimental results could be concordant, plotted very concordantly into the parabola known as Gerber's parabola. He had taken out from the Authors' experiments the constants in the equation for Gerber's parabola,[1] and the constants came out very

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[1] The equation to Gerber's parabola is

$$f_{max} = \frac{\Delta}{2} + \sqrt{(f - n\,\Delta f)}$$

where f_{max} is the greatest stress which can be applied in an indefinitely large number of repetitions, when f is the statical breaking-stress and Δ the range of variation of stress. The Author's experiments give f_{max}, f, and Δ for the case of complete reversal of stress, and therefore permit n to be determined.

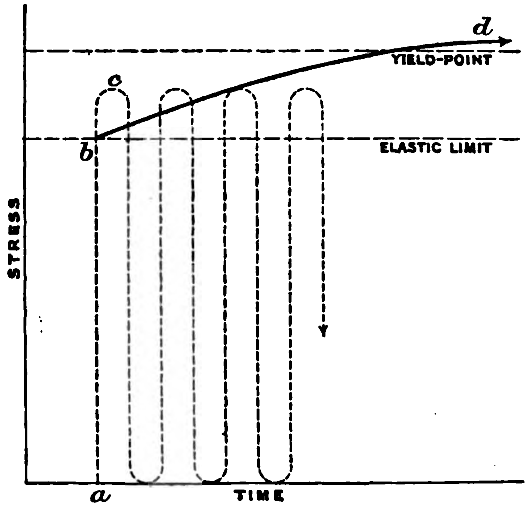
	f	n
Swedish steel, No. 3	47·6	1·47
,, ,, ,, 2	43·8	1·47
,, ,, ,, 1	28·5	1·12
Swedish charcoal iron	19·6	1·07
Piston-rod steel	43·9	1·57
Steel forging	29·5	1·47
Mild steel, No. 2	28·3	1·09
,, ,, ,, 1	21·9	1·16
Wrought iron, No. 1	25·6	1·28
,, ,, ,, 2	23·8	1·24

Some of the values of n are lower than those found by Bauschinger.—W. C. U.

much what they did in Bauschinger's experiments. The lower value Prof. Unwin. of the constant n might be due to the fact that Dr. Stanton's experiments gave only a million changes of stress, whereas Bauschinger's gave five to ten or more millions. Now, it was very uncertain to run a curve through two points only. If some experiments had been made of simple variation of tensile stress by the method which Bauschinger used, there would have been three points available, and there would have been much more certainty that the curve really represented the results. This matter was perhaps the more important because, in Bauschinger's latest researches, in a Paper which did not seem to be known to the Authors and which was published after Bauschinger's death, containing some of the results of 7 years' work shortly before he died, doubt was thrown on the validity of Gerber's parabola. At any rate, information was required not merely as to the range of stress the material would stand with an unlimited number of repetitions of reversal of stress, but as to what range of stress it would stand when there was merely a variation of stress and not complete reversal. A good deal was said in the Paper on what was called the Bauschinger theory. Bauschinger was the first to notice the remarkable variation of the position of the true limit of elasticity—not the yield-point, but the limit of proportionality—when a bar was subjected to straining actions. The important Paper which he wrote in 1885 dealt almost wholly with the effect of variations of tensile stress, and the point which Bauschinger fully made out was illustrated diagrammatically by *Fig. 38*. Suppose a bar subjected to a stress varying between 0 and a limit c above the real primitive elastic limit. The successive applications of the stress were shown by the dotted line. The elastic limit initially at b would rise sometimes above the primitive yield-point as shown by the strong line $b\ d$. Now if d was above the applied stress c, no number of repetitions of stress would break the bar. But if c was above d, the point to which the elastic limit rose, then the bar would break after a certain number of repetitions of stress. That was for variation of stress in one direction, and he thought it was something more than a mere theory, and that the point had been completely made out. In the Paper in question, Bauschinger went on to consider what would happen when there was complete reversal of stress, and there he was on much less secure ground. He found that with a reversal of stress, instead of the true limit of elasticity being raised, it was often lowered, and he formed the impression, from purely statical experiments, that there was a certain natural range of elasticity different from the primitive

Prof. Unwin. range of elasticity which the bar had in the state in which it was received; and he made the further suggestion—it was hardly more—that it would be found that what was called the range between the natural limits of elasticity would be the range which a bar would stand if it were subjected to an unlimited number of repetitions of reversal of stress. As the Authors stated, rather explicitly, that that particular theory of Bauschinger's about reversals of stress was a generally accepted one, he would like to quote some words written by Professor A. Martens about it at a much later date than Bauschinger's Paper—in fact, about 2 or 3 years ago. Professor Martens said: "For the case of alternating tension and

Fig. 38.



compression sufficient knowledge is still lacking, as the phenomena which may be expected to take place under those conditions cannot be identified in Bauschinger's laws." Professor Unwin merely put that in as a word of caution. According to some later experiments it would appear that the Authors had found that the maximum stress which a bar would bear for a million repetitions of loading coincided very closely with the limit of elasticity after that million changes of load. Bauschinger had not quite succeeded in getting that result. He hoped it would prove to be true, because if it did Bauschinger's original suggestion would prove to be a very important step to a true theory. Under the older method of making the tests, they were exceedingly tedious and laborious. The most common method

had been that of using a revolving bar with a weight hung from it, so as to get a reversing bending test. Some time ago it occurred to him that it would be useful to have results on bars tested at different temperatures, and for 2 or 3 years he carried on tests of that kind, keeping a fairly constant temperature round the bar by an air-bath during the day. The tests had to be stopped at night because they could not be watched. He would communicate the results of those tests,[1] not because they were quite satisfactory, but because he thought they were the only tests of their kind, and they did give some information. Broadly, what he had found was that the hot bars really stood variations of stress a little better than the cold bars, though not much. The temperatures reached were between 400° and 500° F. Prof. Unwin.

[1] The following Table gives the results of these tests.—W. C. U.

REPETITION OF STRESS AT DIFFERENT TEMPERATURES.

Rotating-bars approximately ½ inch in diameter and 12 inches long.

—	Material.	Stress.	Range of Stress.	Revolutions to cause Fracture.	Mean Temperature.	Remarks.
		Tons per Sq. Inch.	Tons per Sq. Inch.	No.	° F.	
2,228	Mild steel	±14·25	28·5	1,001,461	Cold	..
2,229	" "	14·78	29·6	1,037,093	"	..
2,230	" "	15·36	30·7	448,622	"	..
2,231	" "	14·91	29·8	1,094,580	202	..
2,232	" "	14·91	29·8	1,041,440	349	..
2,233	" "	14·81	29·6	587,240	449	..
2,244	Mild steel	±15·01	30·0	615,518	Cold	..
2,245	" "	15·02	30·0	790,900	"	..
2,246	" "	15·01	30·0	604,600	"	..
2,253	" "	15·16	30·3	280,550	"	..
2,254	" "	15·00	30·0	172,824	"	..
2,247	" "	15·01	30·0	[953,944]	About 400	Not broken.
2,248	" "	15·01	30·0	[953,944]	" "	" "
2,249	" "	15·02	30·0	[953,944]	" "	" "
2,250	" "	15·02	30·0	663,000	" "	..
2,251	" "	15·16	30·3	560,000	" "	..
2,252	" "	15·16	30·3	595,000	" "	..

Bars 2,228 to 2,233 cut from one bar. Bars 2,244 to 2,254 cut from one bar.
Revolutions, about 150 per minute.

Mr. Blount. Mr. BERTRAM BLOUNT remarked that it was known to many that steel had a higher tensile strength at 400°–500° F. than at the ordinary temperature, and it would not be surprising to find that it resisted the effect of alternations of stress better then than it did at the ordinary temperatures. He thought it very desirable that tests of the kind described in the Paper should be carried out at temperatures above the ordinary, but he knew from experience that that was by no means easy to do. It was difficult to hold in a firm and satisfactory way a test-bar which was being subjected to reciprocating stress, and, at the same time, to heat that bar to a definite temperature without excessive leakage of heat from the ends of the test-bar. With a common tensile test-bar it was a simple matter, as the bar could be made long. The matter should certainly be taken up by the National Physical Laboratory, which had an equipment adequate to carry it out, for it was work of a research character that required to be done. The Paper had raised in his mind the question of the real mechanism of the failure when test-pieces broke, and he congratulated the Authors on having put their finger on the cause in assigning it to slip-bands. There seemed to be no doubt from the photographs that the fracture was a developing one. To begin with, there was some sort of stress in the mass of one part of the metal which induced it to prepare itself, as it were, for a catastrophe. In short, there was a minute incipient crack, something which might manifest itself as a slip-band, and be a potential source of weakness. When alternating stress was applied to that mass of metal, the incipient cracks became real, and after a while very apparent, and presently actual fracture occurred. From the engineering point of view, it was desirable to be able to predict from microscopical examination whether or not a material was at all likely to fail under reciprocating stress. On that point the Authors' experiments were not quite convincing. The subject offered admirable scope for research, but it would doubtless be tedious and difficult to carry out experiments that would be convincing. With them would be collated, of course, the examination of steel of different qualities. The steels which the Authors had examined were of quite ordinary quality, except the one that had been pointed out as being abnormal. He would like to see the research extended to steels of the modern class, such as those used for crank-shafts of motor-car engines—special alloys like vanadium, chromium, and nickel steel—which differed greatly from the ordinary steel used for engineering purposes. He agreed with Professor Unwin that it would have been better if the Authors had taken first the simpler case, namely variation of tensile stress, and had examined

its effect on steels of all classes. However, the Paper was so good that he thanked the Authors sincerely for the excellent results they had given. Mr. Blount.

Mr. JAMES C. INGLIS observed that one or two points arising in ordinary practice appeared to be closely allied to the subject the Authors had investigated. In the first place, it must be a matter of real relief to everyone who had to do with alternating stresses to feel that there was the beginning of a law in regard to the effect of alternating stresses in any material whatever. It used to be a common practice on railways to reverse double-headed rails after they had worn to a certain extent. That practice had now been quite discredited. The theory that had discredited it was, that the continual variation or reversal of the stress—he hardly knew which, because, when a locomotive passed over a rail supported on chairs 2 feet 6 inches apart, it was quite conceivable that according to the intensity of the load the effect might be either reversal or merely variation—was the cause of the many fractures which had occurred on turned rails; and it was now held to be dangerous to reverse a double-headed rail. The breakage might be due to more severe shocks, caused by the irregularity which the bearing of the rail on the chairs produced; but there was a general impression that a change occurred in the molecular structure of the rail, which rendered it less efficient to resist reversals of stress. On a busy line the number of reversals or variations in the life of a fairly heavy rail was about twenty millions. He had examined carefully many of the fractures that had occurred, and he had never been able to see the slip-lines; but if they could be detected it would assist very materially in arriving at some opinion as to the probable life of a rail. It was a curious thing that the ordinary practice of overhauling locomotives had developed into a detailed examination of every part after a locomotive had travelled 60,000 to 80,000 miles; and during that period the reversals of stress in an ordinary locomotive would approximate to twenty millions. A microscopical examination of connecting-rods or piston-rods when they had worked for a certain number of miles would be of great use, and he felt sure all the railways would be only too glad to avail themselves of the critical analysis which could be obtained at the National Physical Laboratory. The Paper treated of specimens which were very small, and it would be interesting to know the effect of variations or reversals, within the limits spoken of, on rather larger masses. For instance, not long ago an accident in which life was lost arose from the breaking of a connecting-rod; and in investigating the cause much turned on the composition and physical condition of the Mr. Inglis.

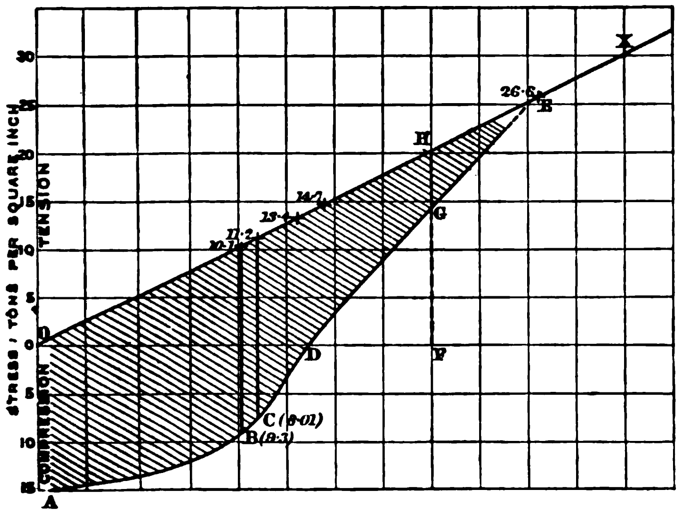
Mr. Inglis. steel. It was tested elaborately and twisted, but he did not know t the mere fact of the metal withstanding the twisting was proof t it was in its original condition. He mentioned that to show t there was a large field for further practical investigation wh would help many people. The railways would be prepared to furn specimens of material which had been under stress for, say, 20 yea and they would be only too thankful to avail themselves of a quan tative examination such as the Paper described.

Sir Alexander Kennedy. Sir ALEXANDER KENNEDY, Vice-President, remarked that it w useful to have something that engineers could fall back upon wh confronted now and then with the popular belief that a piece material must necessarily be fatigued to destruction if it was on stressed often enough. Many people were unable to believe that was not the number of repetitions that killed the material, apar altogether from the amount of stress which they represented. Bu the Authors' curves showed what engineers who had studied th subject knew quite well, namely, that there was a stress below which the load could be repeated innumerable times, so far as was known, without causing ultimate fracture. An interesting question had been raised about the effect of variation of tensile stress as distinguished from a variation of stress from tension to compression. What happened under these conditions might be best illustrated by a diagram such as that in *Fig. 39*, which represented as nearly as possible the conditions of the Authors' "Wrought Iron No. 2." Here compressive stresses were measured downwards, and tensile stresses upwards, from a common base. The material in question had a primitive elastic limit of 13·4 tons, its yield-point was 14·7 tons, and it finally broke at 25·6 tons per square inch. These points were marked upon the diagonal line. The Authors' experiments gave two additional pairs of points, namely, that the material broke down under alternations of 10·1 tons tension and 9·3 tons compression, and also under alternations between 11·2 tons tension and 8·0 tons compression. From these data a curve (marked A B C D E) could be approximately constructed, such that the distance between it and the diagonal line O X should represent the range of stress under which the material broke down under different conditions when the applications of that range of stress were often enough repeated. A point near A represented the elastic limit in compression, the tensile stress being zero. This had not been determined by the Authors, but must have been in the neighbourhood of 15 tons per square inch. The curve must then pass through the points B and C, which were determined by the Authors. It was known also that if the upper limit of tensile stress was approximately

Sir Alexander Kennedy.

equal to the limit of elasticity, the lower limit must be zero, that was to say, that the range of stress was practically equal to the limit of elasticity when the highest stress was equal to that limit. This determined the point D. Beyond this, Wöhler's experiments showed that if the upper limit of tensile stress exceeded the limit of elasticity, the material would stand an unlimited number of applications of load, if the lower limit of tensile stress was at the same time sufficiently raised. There were no data for the particular material in question to determine points in reference to these parts of the curve, but it was known that it must ultimately pass through the point E, the load of which *one* application

Fig. 39.



would cause rupture. The curve illustrated the interesting point raised by Professor Unwin, that if the material were stressed between two tensions (instead of between a tension and a compression) the upper tension might be much greater than the limit of elasticity, or even than the yield-point—in fact, it might be very near to the ordinary breaking-load of the material—provided only that the lower limit were much higher than zero. Assuming, for example, that the curve drawn in the figure was approximately correct, it would appear that the material in question would stand an unlimited application of stresses varying between 14 tons per square inch and 20 tons per square inch, or between 19 tons per square inch and 22 tons per square inch, the range being reduced to 6 tons and 3 tons

Sir Alexander Kennedy.

per square inch respectively, but the upper stress being much greater than the yield-point. It had been suggested in the discussion that the determination of this part of the curve (D E) would be of greater scientific value than the Authors' determinations in the regions B C. He thought, however, that this view of the case was based on an entire misapprehension of the physical facts. Within the region B C D, experimented on by the Authors, the material was in a condition in which it could be used, and was used, practically in construction. But directly the material was brought into such a condition that it could be worked upon the curve D E it had ceased to be constructively useful. It could only be brought into this condition by actually stretching it beyond its limit of elasticity and giving it a not inconsiderable permanent set. For example, the application of stresses between 2 tons and 15 tons per square inch could only go on unlimitedly if the material had already been stretched as much as it would give way at its yield-point, which might be anything between 1 per cent. and 2 per cent. of its whole length. Of course a material so stretched could not exist in a structure. A material in a structure or machine could never be stressed, even a single time, beyond its limit of elasticity without such deformation of the structure or machine as would render it useless. Whether a time would ever come in which engineers would strain all their materials in some preliminary fashion beyond their original limits of elasticity, so as to make them capable of use at higher loads than those limits, he could not say, but that was at any rate outside the region of practical politics at present. It would of course be of much scientific interest if the Authors were able by future experiments to determine points in the curve D E. But he felt sure that such determinations would not help in the practical design of structures or machinery. That was to say, the fact that a material would withstand a stress of 20 tons repeated unlimitedly if this stress alternated with a stress of 14 tons, and not with zero, was of absolutely no practical importance, when for other reasons it was absolutely necessary to keep the maximum limit of stress below 13 tons under all circumstances, as in the particular material under consideration. A part of a structure stressed between 10 tons and 7 tons per square inch was in no way whatever stronger, so far as was known, than if it were stressed between 10 tons per square inch and zero, or, as in the Authors' case, between 9 tons of compression and 10 tons of tension. The arithmetical fact that 10 and 7 had the same ratio as 20 and 14 (as in the illustration just given), had obviously no influence whatever on the result, although this had been, oddly enough, not unfrequently assumed. He himself had made

a number of experiments on the general effect of straining a material beyond its limit of elasticity, and had found that he could make a bar apparently quite elastic and capable of withstanding a certain number of repetitions of loads equal to nine-tenths of its breaking-load, without any measurable permanent set. But then the material so tested was already stretched 3 or 4 per cent. beyond its original length, and was therefore not in a condition which could have any counterpart in structures or machines. Sir Alexander Kennedy.

Dr. T. E. STANTON, in reply, remarked that the nomenclature objected to by Mr. Robertson was not due to the Authors; the term "cast-steel axles" having been taken from the description of Wöhler's work in Professor Unwin's treatise "The Testing of Materials of Construction." With reference to Mr. Robertson's condemnation of the material described as "Mild steel No. 1," he could not agree that this was "rotten," since it had a perfectly definite, though low, limit of resistance to reversals of stress; but the irregularity of the results indicated that it was the least trustworthy of the materials which were tested. There was no mistake in the statement of the results of the analysis of this bar given in Table I, which had been redetermined and found correct. If, therefore, there was any error, it was one of description, that was, possibly the bar from which these specimens were cut was one which had been accidentally placed among others of a different quality; but if that were the case it did not detract from the value of the results given in the Paper, which were those yielded by a material whose correct analysis was stated. In reply to Mr. Robertson's request for information about the behaviour of the bars which had been heat-treated by being raised to 1,000° C. and then cooled slowly in air, the following Table gave the results obtained with the Swedish Bessemer Steel No. 2, which had a carbon content of 0·446 per cent.:— Dr. Stanton.

Material.	Elastic Limit.	Maximum Stress.	Limiting Ranges of Stress.	Remarks.
	Tons per Sq. In.	Tons per Sq. In.	Tons per Sq. In.	
Swedish Bessemer No. 2 .	25·0	43·75	30·4	No heat-treatment.
" " "	19·60	37·70	28·0	Raised to 1,000° C. and cooled in air.

With reference to Professor Unwin and Mr. Blount's criticism that the Authors should have undertaken the investigation of the resistance of the same materials under simple variations of tensile stress, the scientific importance of such work had been fully recog-

Dr. Stanton. nized, but it had not been thought advisable in this Paper, which professedly dealt with questions in the everyday practice of the designer, to make experiments on materials which were permanently deformed at the outset, since it was well known that the maximum stresses reached in such experiments were, in the majority of cases, well above the elastic limit of the material. Further defence of the position which the Authors had taken up in this respect was rendered unnecessary by the contribution of Sir Alexander Kennedy to the discussion, with which the Authors were in complete agreement, and which, coming from such a high authority, they felt would have much more weight than any statement of their own. The Authors were grateful to Professor Unwin for the interesting account of Bauschinger's work which he had given, and they hoped at some future time to go more completely into the investigation of the variations of the elastic limit than they had done in the preliminary work in that direction described in the present Paper. From observations which they had made since the communication of the Paper, they had strong reasons for believing that in cases in which the range of stress was greater than its limiting value, that was, those in which fracture ultimately took place, the limits of elasticity, both in tension and in compression, became smaller as the test proceeded. He thought that the results which Professor Unwin had promised to communicate[1] on the resistance of steel at 400° F. would be most valuable to all designers of heat-engines, especially as information on the effect of temperature was so rare on account of the difficulty in carrying out the experiments. He was indebted to Mr. Inglis for his offer to supply material which had been under stress for a considerable time, and he ventured to hope that, in cases where unexpected failure in structures and machines had occurred, engineers would kindly present samples of the material to the Laboratory for investigation.

Correspondence.

Mr. Breuil. Mr. P. Breuil, of Paris, congratulated the Authors on the important conclusions at which they had arrived. He would refer specially to the one pertaining to the determination of the elastic limit of test-pieces subjected to a large number of alternations of stress.

[1] See foot-note p. 117.—Sec. Inst. C.E.

As this elastic limit was equal to the maximum stress on the test-pieces, it was possible to predict, on determination of this limit in the case of a piece broken in use after a large number of reversals, for how many such reversals it might be depended on. This conclusion, which had been arrived at by statical tests, was now confirmed by the Authors, and gave cause for congratulation. The development of cracks in steel was admirably shown by the Authors. He would advise that they should repeat their tests, not only with sound specimens, but also with palpably poor specimens, which, just on account of their poor quality, were of greater importance. He felt sure that herein would be found the explanation of a host of anomalies exhibited in practice by these metals. The accompanying microphotograph (Fig. 40, Plate 2) depicted a sample of iron, containing 0·5 per cent. of phosphorus, from a part which broke in use after 8 years of stress by bending. It would be noticed that definite flaws, springing from and connecting specks of slag, existed between the particles of iron, which tallied very well with the form of the cracks in the corners of the specimens tested by the Authors; as this microphotograph showed the centre of the specimen, it might be supposed that the study of these deformations, in the case of other faulty specimens, would prove of interest. Mr. Breuil.

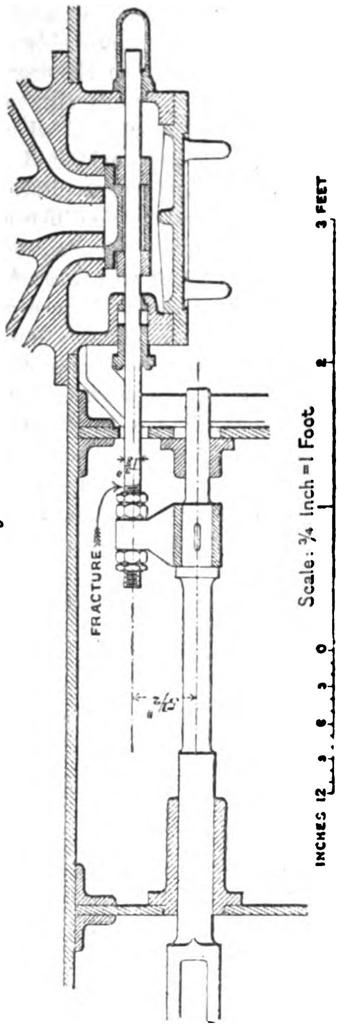
Dr. A. W. Brightmore had not noticed that the following explanation of the phenomena exhibited by metal bars subjected to variations of stress had been definitely brought forward as a satisfactory method of accounting for the results obtained. It would no doubt be readily conceded that such a condition of things as a "uniform distribution" of stress over a cross section of a bar or specimen subjected to the action of a force, notwithstanding all the precautions which might be taken to ensure it, existed only in the imagination. Consequently, whenever a force, however axially it might be applied, acted upon a bar, certain particles in any cross section were stressed to a considerably greater extent than other particles in the same cross section. The excess of this maximum stress over the average stress would of course depend on the lack of homogeneity in the material, assuming that the force was applied axially. Now, if the average stress was in the neighbourhood of the elastic limit of the material, certain particles would be stressed beyond their elastic limit when the force was applied, and would therefore take a permanent set ("slip-lines"). This would cause the distribution of stress on the section to be still less uniform the next time the force was applied; consequently other particles would then come in for more than their share of the stress, and would be stressed beyond Dr. Brightmore.

Dr. Brightmore. their elastic limit, and take a permanent set, again altering the distribution, and increasing the lack of uniformity of the stress the next time the force was applied. Now, it was well known that if a bar was stressed slightly beyond its elastic limit, that limit was raised; and if this process was repeated many times the elastic limit was increased up to the breaking-weight of the material, and the bar finally snapped suddenly. Applying the same reasoning to an individual particle in a cross section of the specimen under consideration, it would be seen that in course of the oft-repeated applications of the force, the turn of such a particle to take stress beyond its increased elastic limit would come round from time to time, as the intensity of the stress over the section became less and less uniform, and it would in course of time fracture. When numbers of these particles near together had fractured, the bar or specimen developed a crack, and finally broke. This explanation received confirmation from the statement by the Authors that in many cases the first set, or sets, of slip-lines observed were not those along which ultimate fracture occurred, or which developed into cracks. From the foregoing it followed that if the force, even though applied axially to a bar, was great enough, allowing for the lack of perfect homogeneity in a section of the bar, to stress some of the particles in a cross section beyond their elastic limit, the bar would ultimately fracture under the repetition of the application of such force. The above considerations explained the superiority in resistance to reversals of stress of homogeneous fine-grained steel over more heterogeneous wrought iron.

Mr. Gillott. Mr. THOMAS GILLOTT remarked that there were few engineers who had not had experience of failures of parts of machinery subjected to alternating stresses, and such cases had often occurred with mild-steel valve-spindles on a number of locomotives formerly under his charge, the driving arrangement being as shown in *Fig. 41.* The valves were of brass, measuring $8\frac{3}{4}$ inches by $14\frac{1}{2}$ inches over the faces, the safety-valve pressure was 140 lbs. per square inch, and in average work the force required to overcome all the resistances would not exceed 1 ton. The valve-spindles were $1\frac{3}{8}$ inch in diameter, turned from rolled bars, and had a screw-thread cut on them for a length of about 7 inches where they were secured to the driving arm; and these spindles broke at the end of the screwed part with a clean smooth fracture as though they had been sheared straight across, no signs of tearing being apparent to the naked eye. In every case when the broken screwed part was bent cold and closed under a steam-hammer, no signs of fracture were apparent at the bottom of the threads. Mr. Gillott could

not remember a single case in which valve-spindles for the same engines, made from best Yorkshire iron, case-hardened, had had to be replaced on account of breaking. This led him to make some remarks on the materials experimented on by the Authors, whose painstaking work he fully appreciated, although he would have preferred some tests on a larger scale. Mr. Gillott had had experience of rolled-steel rounds made at works where the practice was to cast small ingots (*e.g.*, about 4 inches square for $\frac{3}{4}$-inch and $\frac{7}{8}$-inch rods) instead of cogging down larger ingots into billets for the rods to be rolled; and the results had been so unsatisfactory that he had had to discontinue using such material, although the evidence of the testing-machine could be quoted against him. The uncertainties of such steel were small compared with those from "iron" bars made at works where scrap was purchased, and steel and iron were often mixed, although professedly kept separate: some irregularities of this kind might account for the appearance of Fig. 14, Plate 1. Mr. Gillott would be glad if the Authors would describe the appearance of the various fractures on their broken test-bars, and he also asked whether details of the processes of manufacture of the various bars were available. Mr. Gillott.

Fig. 41.



Mr. Henry Le Chatelier, of Paris, considered the Paper to be one of the most important of those to which metallurgists should at the present juncture turn their attention. For a considerable period it had been thought that in a tensile test the elastic limit and the extension sufficed to determine completely the behaviour Mr. Henry Le Chatelier

Mr. Henry Le Chatelier. of a metal under working-conditions. This supposition had now been set aside. Brittleness-tests had shown the small importance of the ultimate elongation at fracture, since specimens giving an elongation of 35 per cent. might in practice break like glass. Tests on reversal of stress probably also showed that the elastic limit had but little influence on the capability of a metal to resist variations in stress such as were always met with in practice. So far the results of the Paper itself, which at present could only be considered a preliminary one, exhibited variations in the ratio of the elastic limit to the resistance to alternations of stress between 1·1 and 1·8, which was a very wide difference. Most likely, on further varying the tests, still greater discrepancies would be noticed. It was a matter for regret that in this first set of tests the Authors had only taken metals in everyday use, whose conditions of manufacture were inadequately detailed. It was impossible from the figures obtained to draw any inferences applicable to other varieties of metals. It was reasonable to suppose, however, that this communication was merely the forerunner of a lengthy set of investigations, extending over a number of years, and carried out in a methodical manner. The study of the variation in the ratio of the elastic limit to the ultimate strength under alternating stresses, while systematically varying the thermal treatment of one and the same metal, would be of considerable practical value; as would also an investigation of the effect of the various metals now introduced in the manufacture of special brands of steel. Did these new kinds of steel really possess that superiority which was often attributed to them? Opinions differed on this point. Some engineers were of the opinion—and exceedingly plausible reasons appeared to confirm their view—that ordinary steels might, for the majority of purposes, yield the same results, but that their thermal treatment required greater accuracy and was beyond the capabilities of some manufacturers. If this view of the matter were adopted, the special brands of steel would be the products of ignorant persons. It would be of great practical importance to thrash out this matter. In any case it was impossible to adequately congratulate the National Physical Laboratory and its Director, Dr. Glazebrook, on the skilful and persevering initiative exhibited by their staff in attacking all problems of general interest to manufacturers. If the utility of the laboratory required any further vindication, the work carried out since its inauguration provided it in a brilliant manner.

Mr. Osmond. Mr. F. OSMOND, of Paris, observed that Bauschinger's idea, which assumed that the elastic limit as usually measured was an artificially raised limit, and that there existed a true lower limit, which appeared under alternations of stress, was exceedingly ingenious

and interesting; it would give an explanation of the yield-point which generally appeared on the curve of deformations under load in the case of iron and mild steels. But, in spite of the Authors' deductions, this idea did not appear to be verified by the results of their tests. Surely, if a true elastic limit existed which was lower than that obtained from tensile tests, this true limit should be a physical constant, independent of the shape of the test-pieces. But the curves of *Fig. 5* showed that the half limiting range of stress was, roughly speaking, doubled in the case of test-pieces of type IV as against test-pieces of type I. True, in the case of specimens which had withstood a large number of reversals of stress without fracture, the Authors found that the elastic limits in both tension and compression were lowered, and practically coincided with the maximum stress imposed during the reversal tests. But, in order to make this determination on a very short test-bar, the Authors employed a specially sensitive extensometer, and it might be that its sensibility was the cause of an apparent diminution. As a matter of fact, Mr. C. Fremont's experiments,[1] which, although the account of them had been translated into English,[2] seemed to be but little known in England, showed that the elastic limit, as usually determined, did not correspond with anything definite. When a small test-bar was subjected either to a tensile or to a compressive test, the load was never distributed uniformly over the whole section, on account of lack of homogeneity or errors in adjustment, and because the line of effort was not absolutely parallel to the axis. This was proved by the fact that in a tensile test certain fibres shortened while others extended, and that small bars of hard steel often broke at the head, outside the least section; and again, the appearance of Lüders lines occurred much below the elastic limit of the test-piece. These lines, easily visible on polished specimens, consisted of mountains and valleys; their mere existence proved that the elastic limit had been exceeded at the points where they appeared, that was, locally. Mr. Osmond had had a series of tests made, which were referred to by Mr. Fremont, on some small test-bars, all of the same mild steel. One bar had been loaded to 5 kilograms per square millimetre (3·2 tons per square inch) and then taken out of the machine; another had been loaded to 8·5 kilograms per square millimetre (5·4 tons per square inch); a third to 12 kilograms per square millimetre (7·62 tons per square inch); and so on, until in the case of the last bar the yield-point had

Mr. Osmond.

[1] "Mesure de la limite élastique des métaux." Bulletin de la Société d'Encouragement, 1903, pt. ii, p. 350.
[2] *Nature*, vol. lxix, p. 276.

Mr. Osmond. been passed. The operations had been carried out under conditions usual in factories, except that the test-pieces were previously polished. The piece loaded to 5 kilograms per square millimetre had shown no traces of Lüders lines. These lines had, however, been plentiful in the case of the specimen loaded to 8·5 kilograms per square millimetre, and on the specimen loaded to 21·5 kilograms per square millimetre (13·65 tons per square inch) the lines had not quite covered the whole surface. The yield-point had been therefore a little greater than this load, and the elastic limit, as determined by accurate instruments, would have been found to be a little less. It followed that the elastic limit had been *locally* exceeded under a mean load about one-third as great. With sufficient accuracy, it should have been possible to find an elastic limit less than 8·5 kilograms per square millimetre, but this latter would not have been that of the metal itself, but that of the test-piece, for the conditions under which the test was made—that was, when the obliquity of the tension, the heterogeneity of the material, and errors in adjustment of the piece and the ends of the piece, were taken into account, all of these being inevitable defects. On a specimen presenting points of weakness, such as a screw-thread or a groove, the differences would have been still greater. Now, was there any connection between the statical stresses which usually determined what was known as the elastic limit and the dynamical stresses brought into play in Wöhler's experiments? Nothing could be less certain. It was thought that rupture due to reversals of stress should only occur if the elastic limit, as determined by a statical test, had been exceeded. But in a statical test, a load was applied to the metal, which was measured in units of weight; in tests with reversals of stress, work done was measured in kilogram-metres. The two units had different dimensions. Kilogram-metres were the product of two quantities, the one being the instantaneous pressure due to shock; but if the product was known, the two factors were unknown. In Mr. Osmond's opinion, it was necessary, in order to cause rupture, for the instantaneous pressure due to shock or vibration to considerably exceed the elastic limit as determined by a tensile test, and to attain at the point of greatest fatigue the breaking stress—not the maximum load divided by the initial area, but the load at the moment of rupture divided by the contracted area. According to Mr. Considère's researches,[1] this stress, for a mild steel, was 71·6 kilograms per square millimetre (45·4 tons per square inch), whereas the ordinary method of calculation gave

[1] "Mémoire sur l'emploi du fer et de l'acier dans les constructions," *Annales des Ponts et Chaussées*, 6th series, vol. ix (1885), p. 574.

40·3 kilograms per square millimetre (25·6 tons per square inch). Mr. Osmond.
This theory appeared to be confirmed by the Authors' tests. They found, as a matter of fact, that the resistance to reversals of stress did not depend on the maximum tensile or compressive stress, but on the range between the maximum tensile and compressive stresses. Wöhler and Bauschinger had arrived at the same conclusions. It followed that a given sample, *e.g.*, the Authors' "Wrought iron No. 2," the limiting range of which was 19·2 tons per square inch, could withstand this stress of 19·2 tons per square inch in tension for an indefinite period, provided the compressive stress was made equal to zero, and this in spite of the fact that the primitive elastic limit (Table II) was only 13·37 tons per square inch. Statical stresses caused rupture after the preliminary deformation; shock and vibration caused it without preliminary deformation. The two processes had nothing in common, although in practice they were superimposed. It followed that statical tests were quite insufficient to determine the quality of a metal intended to resist dynamical stresses, and that the use of Wöhler's or an equivalent method (such as, for example, impact tests on notched bars). was not only advisable, but also absolutely necessary. Too much dependence, however, must not be placed on the limiting range, measured under fixed conditions. It might no longer be accurate under different conditions, and the Authors themselves gave a conclusive proof of this. Under certain conditions they obtained a limiting range 9 per cent. below the normal, and sometimes considerably less than that. They attributed this to the coincidence of the period of the machines with the period of vibration of the specimen, and this explanation was quite satisfactory. But why should not this coincidence, which occurred accidentally in certain tests, occur in a bridge when a train passed over it, or in a number of other cases easy to enumerate? This seemed to be an extremely important point. Why should the high limiting range be more accurate than the low one? If the lowest limiting range had been able to occur, then it could occur also in practice; further, there was nothing to show that even this was the lowest one possible, and prudence did not permit of neglecting it. It was this latter value that must be taken as a maximum—too high a one, perhaps, but one that should never be exceeded unless the coincidence of the periods of vibration that brought it about was absent. In the matter of elementary deformations, the Authors confirmed the observations of Messrs. Ewing and Humfrey. These observations, were, moreover, perfectly accurate and practically indisputable, yet Mr. Osmond,

Mr. Osmond. like Messrs. Fremont and Cartaud,[1] was of opinion that they should be somewhat otherwise interpreted. Messrs. Ewing and Humfrey thought the lines of fracture to be developments of the slip-bands. As a matter of fact, these lines were not of the same character. The latter corresponded to statical deformations: they were not of crystallographic origin, as was proved by the photograph reproduced in Fig. 42, Plate 2, which depicted a plane of cleavage of a crystal of iron; the point of a needle had been pressed on to this polished surface under a load of 1·5 kilogram (3·3 lbs.); this pressure had caused the formation of a cross, the branches of which, consisting of a number of lines, ran parallel to the diagonals of the square plane of cubic cleavage. A general deformation by compression therefore occurred, developing new lines called "slip-bands" by Messrs. Ewing and Humfrey. According to Mr. Rosenhain these lines were parallel to the faces of a regular octahedron, as indeed was the case with copper, gold, silver, platinum, and lead. They should, accordingly, also be parallel, on the face of the cube, to the branches of the cross. The figure showed at once that there was no sign of this, and, moreover, that these lines were not straight.[2] On the other hand, lines along which rupture due to reversals of stress took place were straight and of crystallographic origin; they were either cleavage lines of a cube or a series of macles known as Neumann's lamellæ; they showed up when etched with acid, whereas the slip-bands did not do so unless the deformation had been carried very far. Besides, it was quite natural for these various lines to become superimposed at the same spot, which was thus shown to be the place of maximum fatigue. They were nevertheless different, and the latter only were dangerous. It was important to discriminate between them.

The Authors. The AUTHORS, in reply to the Correspondence, observed that the wide range in the values of the ratio of the elastic limit to the resistance under alternations of stress, pointed out by Mr. Le Chatelier, was no doubt due to the artificial positions of the primitive elastic limits. As an instance of this, a sample of the Swedish Bessemer Steel No. 1, which had a primitive elastic limit of 21·4 tons per square inch, was raised to 1,000° C., and then cooled slowly in air. Its elastic limit had then been found to be 11·6 tons per square inch, and its limiting range of stress for one million reversals

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[1] *Revue de Métallurgie*, January, 1904.

[2] One branch of the cross is badly formed, probably because the needle was not absolutely perpendicular to the surface. The two large parallel black lines running across the mouth of the puncture are purely accidental and of no special import.—F.O.

approximately 18·5 tons, so that the heat-treatment had brought about a change in the value of the ratio from 1·25 to 1·60. Mr. Osmond appeared to be of opinion that the natural elastic limits determined by reversals of stress should, if they existed at all, be physical constants independent of the form of the specimen, and hence was unable to reconcile the differences between the limiting ranges of the stress for specimens of types I and IV. The Authors would point out, however, that agreement of the ranges of stress for different forms of the same material could only occur if the distribution of stress over the sections of the specimens were identical in the two cases. Now, in the case of a specimen with a sudden change of section, although the mean stress over the section might be the same as in a specimen of maximum resistance, the actual intensity of the stress at the sharp corners was higher than that which existed in the specimen of maximum resistance. This conclusion was, they thought, inevitable from the evidence in the photograph forming Fig. 28, Plate 2, and fully accounted for the low range of stress obtained. The existence of such a physical constant must be sought for in the results of experiments in which the distribution of stress in the specimen was approximately uniform, and there was no evidence in the present research that this constant did not exist. Mr. Osmond had apparently not appreciated the method of application of the stress to the specimens on the testing-machine described in the Paper, since he referred to the "instantaneous pressure due to shock" on the specimens. In the machine used the stress was produced by the acceleration of a definite mass attached to the specimen and caused by it to move in an approximately simple harmonic manner, so that there was no "shock" on the specimen in any way. The Authors could not agree with Dr. Brightmore's theory that a small local permanent set in a specimen under test, which was due to the line of action of the load not being strictly axial, would cause the distribution of stress to be still less uniform the next time the load was applied. Their observations led them to the conclusion that a slipping in certain crystals had the effect of distributing the stress more evenly and of temporarily preventing the deterioration of the specimen at that section. An apparent illustration of this action had been noticed in the Paper (p. 100, and Figs. 31 and 32, Plate 2). In reply to Mr. Gillott's question as to the appearance of the fractures of the various specimens, these had the same characteristics in the hard and soft materials alike. There was no permanent elongation of the specimen, the fracture being of the nature of a sharp-edged crack across the specimen. In some cases the plane of the fracture was normal to the axis of the

The Authors.

The Authors. specimen, and in other cases inclined to it—in the extreme cases, at an angle of 30° or 40°. The Authors had communicated Mr. Gillott's inquiry for details of manufacture of the bars to Mr. Hadfield, who had replied that the bars which he supplied were produced by the ordinary Swedish Bessemer method. There was nothing special about their manufacture. The Authors desired to thank Mr. Osmond and Mr. Breuil for the photomicrographs which they had sent for publication in the Correspondence, both of which afforded valuable evidence of the manner of failure of materials under stress.

ANNUAL GENERAL MEETING.

24 April, 1906.

Sir ALEXANDER RICHARDSON BINNIE, President, in the Chair.

The Notice convening the Meeting was taken as read, as well as the Minutes of the Annual General Meeting of the 18th April, 1905, which the President was authorized to sign.

The Report of the Council upon the Proceedings of The Institution during the Session 1905–1906 was read, the Statement of Accounts being taken as read.

After consideration, it was resolved,—That the Report of the Council be received and approved, and that it be printed in the Minutes of Proceedings.

The Scrutineers reported the election of the Council for 1906–1907 as follows [1]:—

President.

Sir ALEXANDER BLACKIE WILLIAM KENNEDY, LL.D., F.R.S.

Vice-Presidents.

William Robert Galbraith.
William Matthews, C.M.G.
Sir Edward Leader Williams.
James Charles Inglis.

Other Members of Council.

William Patrick Anderson.
John Benton, C.I.E.
Benjamin Hall Blyth, M.A.
Cuthbert Arthur Brereton.
Robert Elliott-Cooper.
Rookes Evelyn Bell Crompton, C.B.
Joseph Davis.
George Frederick Deacon, LL.D.
Francis Elgar, LL.D., F.R.S.
Maurice Fitzmaurice, C.M.G., M.A., M.A.I.
Robert Abbott Hadfield.
George Henry Hill.
Walter Hunter.
George Robert Jebb.
John Henry Johns.
Sir William Thomas Lewis, *Bart.*
Sir George Thomas Livesey.
Anthony George Lyster.
Sir Andrew Noble, *Bart.*, K.C.B.
The Hon. Charles Algernon Parsons, C.B., F.R.S.
Alexander Ross.
Alexander Siemens.
John Strain.
Sir John Isaac Thornycroft, LL.D., F.R.S.
William Cawthorne Unwin, B.Sc., LL.D., F.R.S.
Alfred Fernandez Yarrow.

[1] The Council commence their year of office on the first Tuesday in November, 1906.

Resolved,—That the thanks of the Meeting be given to t Scrutineers, and that the Ballot-Papers be destroyed.

Mr. A. W. Szlumper responded on behalf of the Scrutineers.

Resolved,—That the thanks of the Institution be given Messrs. P. D. Griffiths and J. M. Dobson, for their care auditing the Accounts for the past financial year; especially Mr. J. M. Dobson for his gratuitous service in the matter; ar that those gentlemen be re-appointed Auditors for the curre financial year.

Mr. Dobson acknowledged the Resolution.

Resolved,—That the thanks of this Meeting be accorded Sir Alexander Richardson Binnie, President, for his conduct of tl business as Chairman of the Meeting.

The President acknowledged the Resolution.

The proceedings then ended.

REPORT OF THE COUNCIL, 1905–1906.

In reporting upon the present state of The Institution, the Council have not to record any important developments during the past year; but they place before the members a short account of a considerable volume of routine work that has been satisfactorily accomplished.

The establishment of a standard of efficiency for internal-combustion engines is of the first importance in practical thermodynamics. The Council are now able to present to The Institution the completed Report[1] of the Committee on this subject, with confidence that its findings will exercise a useful influence on that form of the application of power. To their colleague, Professor Unwin, and to the Members of the Committee who have acted under his Chairmanship, the Council tender the thanks of The Institution for the result achieved by them.

The reception by the Council of the Report[2] of the Special Committee appointed in 1903, under the Chairmanship of Sir William White, to investigate the complex and difficult questions involved in the proper education and training of engineers, may be considered to mark the Session as one of special interest. The aim of the Council during many years has been to justify the claim of The Institution to be broadly representative of the engineering profession. The issues dealt with in the Report have been conceived in this spirit, the Committee having enjoyed the collaboration of official representatives and prominent members of the principal engineering institutions in Great Britain; and an earnest endeavour has been made to condense into a practical shape a great number of useful but frequently conflicting views, which beset the subject of education and training for the profession of engineering.

Without trenching upon the ground properly occupied by teachers, in respect of the methods of imparting general and scientific knowledge, the Report sets forth the general schemes of education and training which appear to be adapted to secure the best results at the present day. It cannot fail to be especially satisfactory to The Institution that the Report, whilst naturally dealing at considerable length with the newer aspects of scientific education, affirms in a

[1] Minutes of Proceedings Inst. C.E., vol. clxiii, p. 241.

[2] *Post*, p. 159.

most definite manner the principle that a proper course of experience under practical conditions of work is essential to the making of an engineer.

To the Chairman of the Committee, and to all its members—especially those who have served as representatives of other engineering institutions—as well as to the several hundred gentlemen on whose opinions and advice the Committee's judgments have been formed, the grateful thanks of The Institution are due.

The favour in which the Examinations continue to be held is exemplified by a total attendance of 579 candidates during the year. Of the 269 persons passed for election as Associate Members during the Session, 183 had qualified by means of The Institution Examination, whilst 64 were passed on other (exempting) qualifications. Of the 334 Students admitted, 170 had passed the Institution Examination, the remainder being passed on exempting certificates and diplomas. It is an aim of the Council to promote a uniform standard in the subjects of its own examinations and those of all the examinations recognized as exempting therefrom. There is satisfactory evidence that the former are well suited to deal, on these lines, with that numerous class of engineering students who cannot or do not choose to pursue the complete curricula of recognized colleges and universities, and who acquire their scientific knowledge largely by private study.

A Special Committee appointed at the beginning of the Session has formulated the general conditions under which the Yarrow Scholarships will be awarded by the Council (Appendix I) and on its recommendation the Council have awarded scholarships of £70 per annum for 3 years, to enable three deserving Students of The Institution to complete their engineering training.

The Council have received from the Board of Direction of the American Society of Civil Engineers a courteous intimation that members of The Institution who may visit New York will be very welcome to the use of the premises of that Society during their stay there.

Steps have been taken to place in the forthcoming Milan Exhibition a panel commemorative of The Institution, and expressive of the debt which the Engineering profession owes to Italian engineers, and the goodwill The Institution bears to their country.

The Council regret to report that their efforts to procure amendment of the conditions relating to the employment of engineers by urban authorities, in which matter they are in entire sympathy with those members who addressed them on the subject last year, have so far proved unavailing.

They have had before them in the course of the Session two other memorials signed by a number of members of The Institution.

With respect to one of these, the Council have, after full consideration, reaffirmed a former decision, to the effect that it would be inimical to the best interests of The Institution to lay down regulations and rates of charges for professional work. The other memorial submitted a proposal that the several Associations of Students should be transformed into local branches of The Institution. The Council are most desirous of doing all in their power to assist the Student class, in the special interest of which these Associations have been formed; but they are of opinion that the proposal would not be advantageous to that class, and it would be at variance with some important features of the established policy of The Institution.

It has been decided to remit to the incoming Council a proposal that a fourth Engineering Conference be held in the summer of 1907.

The total Roll of The Institution at the date of this Report is 8,165.

The Roll.

The changes which took place in the Roll during the financial year ended the 31st March, 1906, are shown in the accompanying Table.

—	1 April, 1904, to 31 March, 1905.						1 April, 1905, to 31 March, 1906.					
	Honorary Members.	Members.	Associate Members.	Associates.	Students.	Totals.	Honorary Members.	Members.	Associate Members.	Associates.	Students.	Totals.
Numbers at commencement	19	2176	4050	273	1115	7633	20	2249	4117	270	1207	7863
Transferred to Members	..	98	98	..	..		..	88	88	..	..	
Elections	1	49	246	15	..		..	35	257	9	..	
Admissions	..	..	..	..	310	626	..	..	..	..	334	645
Restored to Register	..	3	2	..	..		..	2	7	1	..	
Deceased	..	57	34	9	2		..	59	42	4	5	
Resigned	..	15	28	7	16		..	20	25	7	13	
Erased	..	5	21	2	12		..	3	39	2	6	
Elected Associate Members	..	..	..	..	73	396	..	..	..	..	71	440
Removed—over age	..	..	..	..	115	230	..	..	..	..	144	205
Numbers at termination	20	2249	4117	270	1207	7863	20	2292	4187	267	1302	8068

The elections comprised 35 Members, 257 Associate Members, and 9 Associates; 334 candidates were admitted as Students, and the names of 3 Members, 7 Associate Members and 1 Associate were restored to the register. From this addition of 645 must be deducted the deaths, resignations and erasures during the year, and the Students elected Associate Members, and those who, having passed the age limit of that class, ceased to belong to The Institution, amounting to 440 in all, leaving a net increase of 205.

Among the deceases, the Council record with regret those of Mr. George Robert Stephenson and Mr. James Mansergh, Past-Presidents, Mr. Charles Napier Bell, Member of Council, and Sir William Shelford and Mr. John Brown, former Members of Council.

The full list of deceases is as follows:—

Members.—Alexander Beazeley; Charles Napier Bell; Henry William Brock; John Brown, C.M.G.; Oswald Brown; Thomas Procter Campbell; *Sir* Edward Hamer Carbutt, *Bart.*; George William Catt; Henry James Coles; William Henry Robinson Crabtree; Henry Wheeler Davis; William Dean; Gavin Gemmel Dick; Alexander Duncanson; David Evans; George Foot; George Leedham Fuller; Henry Alfred Gray; William Henry Greenwood; Charles Townshend Hargrave; Henry James Bennet Hargrave, M.A.; George William Harris; Thomas Hayward; Archibald Potter Head; Frederick Benbow Hebbert; James Lennox Houston; Henry Joseph Johnston; Peyton Jones; George Kilgour; Maurice King; John Kyle; George Lewis; William Lloyd; Charles Harlowe Lowe; Francis Joseph Lynch; Robert Knox MacBride; John Stevenson Macintyre; William McLandsborough; James Mansergh, F.R.S.; William Prime Marshall; Alfred Morcom; Robert Bellechasse Morison; John O'Connell; John Price; William Henry Price; Henry Prince; David Richmond, B.A.; David James Ross; Henry James Rouse; *Right Hon. Sir* Bernhard Samuelson, *Bart.*; Philip Edward Sewell; Francis Webb Wentworth-Sheilds; *Sir* William Shelford, K.C.M.G.; Frederic George Slessor; Alexander Arthur Dalrymple Smith; George Robert Stephenson; Charles Radcliffe Thursby; James Edward Tuit; Charles Fitzwilliam White.

Associate Members.—Francis William Allen; Justin Victor Wilfrid Amor; Charles Christopher Carleton Baynes; Charles Revill Bellamy; George Ernest Bergman; Thomas Moyles Bigley; Charles Bewicke Blackburn, B.Sc.; James William Blackett; Percival Noel Boscawen; John Bowden; Percy William Britton; Albert Edward Broad; James Beaumont Buchanan; John Carline; Harry George Christ; Harry Withers Chubb; Arthur Fawcett; Arthur Hill Godfrey; Edward Baker Green; Charles Gulland; George Dallas Marston; Samuel Mather; Cuningham Wilson Moore; Henry Allan Moss; Percy Nevill; John Newman; Henry Cecil Earle Newton; Arthur Oughterson, B.A.; Thomas Perham; John Gordon Pope; Alexander Brown Portus; Frederick Reilly; Hamlet Roberts; Frederick Slade; George Hurst Stanger; Ernest Sykes; Gerard Philip Torrens; Thompson Whitworth; James Wilson *Pasha*; Edmund Richard Window; Douglas Haliburton Windsor; Joseph Henry Woolcock.

Associates.—John Mackay; Joseph Phillips; *Sir* William James Lloyd Wharton; Joseph Wright.

The following resignations have been received:—

Members.—Charles John Bond; Edward Alexander Cameron; William Samuel Child; John Bruce Crawfurd; John Hardisty; Matthew Wilson Hervey; Arthur Edmund Breton Hill, B.A.Sc.; John Edward Hilton; William Henry King; Albert Latham; Edmund Gerald James McCudden; Henry Augustine Fitzgerald MacLeod; Robert Alfred Molloy; John Monthermer Montague, M.A.; Walter Campbell de Morgan; Walter Hawkins Nightingale; Peter Scott; George Hunter Tait; Gerald Edward Wellesley; William Barton Wright.

Associate Members.—James Hartley Abbott; Berulf Watson Beever; George Murray Campbell; *Sir* Robert Cockburn; Joseph Basil Denison; Frederick Robert Foot; John Reed Fothergill; William Augustus Francken; Thomas William Franks; Arthur John Lund Grimes; Victor Hansard Hansard; George Edward Jarvis; William Jopp; John Linacre; Angus Roderick Macdonald; Henry Ough; Henry Parker; William Henry Radford; Reuben William Roberts; Richard Gabbett Spiers Roberts; Henry William Sanford; Herbert George Hammond Spencer; Herman Tapley; William Walter Williams; William Yuill.

Associates.—Samuel Chatwood; *Lord* Derwent; Frederick Henry Grinlinton; *Sir* George Ernest Paget; *Captain* Reginald Ernest Picton; *Major* Edgar Charles Spilsbury; *General Sir* Charles Warren.

Finance.

The Statements of Accounts for the year ending the 31st March, 1906, duly audited, will be found at pp. 146–153.

The receipts on Income Account amounted to £26,092 5*s.* 11*d.*, as against £25,196 2*s.* 10*d.*, last year; on Capital Account (admission fees and life compositions) £3,332 14*s.*; from Trust Funds, £808 6*s.* 11*d.*; the total receipts being £30,233 6*s.* 10*d.*, exclusive of £6,025 12*s.* 10*d.* received for the purposes of the Engineering Standards Committee. The receipts on Income Account included subscriptions £20,729 10*s.*, dividends £2,174 11*s.*, and rents £1,055 15*s.* 7*d.*

The expenditure on Income Account was £22,744 19*s.* 5*d.*, exclusive of £4,700 paid over to the Engineering Standards Committee.

On Capital Account the sum of £5,025 8*s.* 6*d.* was invested in £5,400 London County three per cent. Stock; and the expenditure on Trust Funds account amounted to £546 18*s.* 6*d.*

The nominal value of the investments on Institution account was £79,300, purchased for £79,520 2*s.* 2*d.*; and on Trust Funds account £29,116 4*s.* 9*d.* (nominal value). The present mean market value of The Institution investments is £76,839.

Meetings.

Twenty-one Ordinary Meetings were held during the Session. The first was, as usual, devoted to the President's Address to the members, and at the remaining meetings twelve Papers were con-

sidered. Probably the most noteworthy feature of the proceedings of this Session is the amount of time which has been occupied in the discussion of the subject of the improvement of existing means of communication to meet the requirements of traffic at the present day. While presenting important problems of an engineering character, these questions are fraught with highly complex administrative and financial considerations; consequently the four Papers dealing with this subject have raised discussions of very wide general interest. Mr. J. A. Saner, in his Paper "On Waterways in Great Britain," dealt with the present position of the system of canal navigation in this country and the possibilities of its improvement and reorganization; the information furnished in the Paper and by the discussion thereon cannot fail to prove of service in the elucidation of that subject. Mr. G. R. Jebb, in a Paper entitled "A Plea for Better Country Roads," and Mr. J. E. Blackwall, in his Paper on "Country Roads for Modern Traffic," discussed briefly the question of improved construction and better maintenance of the highways of the country, a matter which has been prominently brought to the attention of engineers and of the public generally by the rapid growth of the use of self-propelled vehicles. Sir Frederick Upcott, in his Paper "The Railway-Gauges of India," brought again before The Institution a subject which has been discussed at length on two previous occasions. When the first of these discussions took place, in 1873, the main question was whether railways of different gauges should be built in India. In the intervening thirty-three years, many thousand miles of railway line of various gauges have been constructed over that country; and the question submitted by Sir Frederick Upcott was the possibility of gradually attaining some uniformity of gauge and the advantages to be gained thereby. Turning next to Papers of a more purely engineering nature, two may be mentioned which relate to somewhat novel construction, namely, that by Mr. J. J. Webster on "The Widnes and Runcorn Transporter Bridge," which described the establishment of communication across a wide river, on a principle of which no previous example has been carried out in this country; and the Paper by Mr. H. Shelford Bidwell, entitled "The Outer Barrier, Hodbarrow Iron Mines," which gave an account of the construction of an embankment, at a cost of more than half a million sterling, for the purpose of enabling valuable iron-ore deposits lying under the foreshore to be worked in safety. Subjects of a mechanical nature were brought forward in two Papers. The Hon. Charles A. Parsons and Mr. G. G. Stoney, in their communication on "The Steam-Turbine," dealt principally with points relating to economy of working and with the development and progress of the steam-

turbine as applied to the propulsion of ships, tracing briefly the history of this application of power, from the first trials with the "Turbinia," in 1897, to the gigantic Atlantic liners now under construction for the Cunard Steamship Company, each of 70,000 I.HP. Mr. H. A. Mavor, dealing with the subject of "Heat-Economy in Factories," suggested a method of examining and recording the distribution of heat-energy generated in large works, where not only power but also heating and drying are required in manufacturing processes, with a view to facilitate the solution of problems connected with the selection and arrangement of plant for economical working. The Paper by Mr. D. E. Lloyd-Davies, on "The Elimination of Storm-Water from Sewerage Systems," presented an attempt to place upon a defined basis the design of sewerage systems with reference to the storm-water flow. In conjunction with this Paper a communication by Col. A. S. Jones and Dr. W. O. Travis, entitled "The Elimination of Suspended Solids and Colloidal matters from Sewage," was considered, in which was put forward a means of dealing with the clogging of bacteria-beds. Mr. C. W. Methven's Paper on "The Harbours of South Africa; with special reference to the Cause and Treatment of Sand-Bars," traced the development of existing harbours in South Africa, and discussed some of the measures for maintaining them, as well as the physical features of the south-eastern coast of Africa and possible sites for future harbours. At the last meeting of the Session, Dr. T. E. Stanton and Mr. Leonard Bairstow presented a communication entitled "The Resistance of Iron and Steel to Reversals of Direct Stress," which recorded the results of a scientific investigation carried out by the Authors at the National Physical Laboratory. Several Papers which it had been intended to consider during the Session under review have had to be held over, owing to the considerable amount of time occupied by some of the discussions. It is intended to bring them forward early next Session.

The Council desire to express their especial thanks to their colleagues, the Hon. Charles A. Parsons and Mr. G. R. Jebb, for the Papers contributed by them.

For some of the Papers read the Council have awarded Medals or Premiums to Messrs. J. A. Saner, G. G. Stoney, T. E. Stanton, L. Bairstow, H. S. Bidwell, J. J. Webster, C. W. Methven, H. A. Mavor, Sir Frederick Upcott, and Mr. D. E. Lloyd-Davies.

These awards, and those which will be made in the autumn in respect of the Papers to be published in Section II of the Proceedings, will be presented at the opening meeting of the next Session.

"James Forrest" Lecture.

Mr. R. A. Hadfield, Member of Council, has consented to deliver the "James Forrest" Lecture for the current year, which is the fourteenth discourse of the series. He will treat "Unsolved Problems in Metallurgy," the date being fixed for the 2nd May.

Students' Meetings and Visits to Works.

During the Session nine Students' Meetings have been held in London. At that held on the 12th January Professor J. D. Cormack, B.Sc., Assoc. M. Inst. C.E., delivered a valuable address on "The Theory of Machines," a copy of which has been furnished to every Student; and at the remaining Meetings nine Students' Papers have been read and discussed. Including the work of the Associations of Students in the provinces, twenty-eight Papers have been read by Students during the Session, twenty-one of which are submitted in competition for the Miller prizes. As in previous years, visits have been paid to engineering works fortnightly during the Session.

The average attendance of Students at meetings and at visits to works, and the average number of speakers in the discussions at Students' Meetings in London, for the past four Sessions, are shown in the following Table:—

Session.	1902–1903	1903–1904	1904–1905	1905–1906
Attendance at meetings .	44	32	45	38
" " visits . . .	19	18	21	21
Speakers at meetings . .	6·5	6·5	7·0	5·4

Although the past Session shows a decrease in the average number of speakers at the meetings, continued improvement has been noticeable in the discussions.

A special series of Students' Visits was arranged for the 4th and 5th April, when a number of Students from the country came to London to take part in the visits and to attend the Students' Thirty-First Annual Dinner, which was held in the evening of the 5th April.

The number of the local Associations has been recently increased to six by the formation of the Bristol, West of England and South Wales Association of Students of The Institution. The

Associations continue to do excellent work, and the Papers presented to them have been sufficient to prevent their having need to avail themselves of the privilege whereby Papers selected for publication in Section II of the "Proceedings" may be placed at their disposal for reading and discussion.

The Library.

The Supplemental Author Catalogue for the period 1895 to 1904, was sent to press in March, 1906, and copies are now available. A Subject Catalogue covering the corresponding period is in course of preparation by the Superintendent of the Library, and will be completed, it is expected, towards the end of this year. During the Session a large number of books have been rebound or repaired, and attention in this respect will shortly have been paid to the entire contents of the Library. There is in progress a general stock-taking of the books—a necessary undertaking which more pressing work has deferred for many years.

It is probably not generally known that the Library possesses several rare and valuable books, among which may be mentioned thirty-nine editions of the Works of Vitruvius (in Latin, Italian, English, French, German and Spanish), Agricola's *De re Metallica*, the *De Magnete* of William Gilbert of Colchester, the MS. of the poet Southey's "Journal of a Tour in Scotland," the MSS. of Smeaton's "Machine Letters," several MSS. of Telford, and the First Account Book of The Institution, containing a statement of the disbursements made in connection with its earliest meeting. These books, and some others which are irreplaceable, have been put under lock and key for security, but may be seen by members on application to the Superintendent of the Library. Rare works of reference, and ordinary text-books, which are in constant demand by readers, are not lent; and it is only under special circumstances that permission can be given for the loan of other books to persons who are unable to consult them in the Library.

A list of Pictures in the possession of The Institution is given with this Report (Appendix II), and the Report on The Education and Training of Engineers is added as a supplement to it.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.					£	s.	d.	£	s.	d.
To Balance, 1 April, 1905, viz. :—										
On Deposit					5,000	0	0			
Cash in the hands of the Treasurer . . .					2,064	1	2			
" " " Secretary . . .						8	8			
								7,064	9	10
INCOME.										
— Subscriptions received :—		£	s.	d.						
Arrears, prior to 1 January, 1905		440	9	6						
For the year 1905		5,723	11	6						
For the year 1906		14,552	11	0						
Advance.		12	18	0						
					20,729	10	0			
— Minutes of Proceedings :—Repayment for Binding, &c.					567	8	0			
— Library Fund					401	16	1			
— Library Catalogue					4	16	0			
— Dividends : 1 year on										
£		*Institution Dividends.*								
10,000	2½% Consols	237	10	0						
4,000	London County 3% Stock	114	0	0						
4,000	Manchester Corporation 3% Stock	114	0	0						
6,000	Metropolitan 3½% Stock	199	10	0						
3,000	Metropolitan Water Board 3% Stock . .	85	10	0						
6,000	Great Eastern Railway 4% Debenture Stock .	228	0	0						
8,000	Great Northern Ry. 3% Debenture Stock . .	228	0	0						
8,000	Great Western Ry. 4% Debenture Stock . .	304	0	0						
8,000	Lancs. & Yorks. Ry. 3% Debenture Stock . .	228	0	0						
7,300	London & N.W. Ry. 3% Debenture Stock . .	208	1	0						
9,600	Midland Ry. 2½% Debenture Stock. . .	228	0	0						
	New Purchase.									
5,400	London County 3% Stock	0	0	0						
					2,174	11	0			
£79,300	Nominal or par value.									
— Refund of Income Tax to 5 Apr. 1905 . . .					109	2	1			
— Rents—No. 27 Great George Street . . .					1,055	15	7			
— Examination Fees					999	1	6			
— Interest on Deposit					50	5	8			
								26,092	5	11
Carried forward								£33,156	15	9

from the 1st APRIL, 1905, *to the* 31st MARCH, 1906.

EXPENDITURE.

Cr. GENERAL EXPENDITURE.

	£ s. d.	£ s. d.	£ s. d.
By House and Establishment Charges:—			
Repairs:—General	57 14 0		
No. 27 Gt. George St., and agents' charges for letting offices .	27 19 6		
		85 13 6	
Rent of No. 27 Great George Street		600 0 0	
Rates and Taxes:—The Institution	1,155 16 8		
No. 27 Gt. George St.	243 2 6		
		1,398 19 2	
Insurance:—The Institution . .	84 5 0		
No. 27 Gt. George St.	4 12 0		
		88 17 0	
Fixtures and Furniture		71 8 6	
Lighting, Warming and Ventilating:—			
The Institution . .	419 3 11		
No. 27 Gt. George St.	15 6 2		
		434 10 1	
Charges for Water (including lifts), Rent of Telephone, &c.	100 17 0		
Charges for Water, No. 27 Great George Street	20 11 0		
		121 8 0	
Refreshments at Meetings		81 3 10	
Assistance at Meetings		30 10 6	
Students' Meetings (including refreshments), Donation to Annual Dinner, and Visits . . .		461 9 3	
Household Expenses		492 7 10	
			3,866 7 8
— Postages, Telegrams, and Parcels		406 18 5	
— Stationery and Printing		1,272 0 9	
— Diplomas		31 6 6	
— Watt Medals		28 0 0	
— Stephenson Medals		28 0 0	
— Annual Dinner (Balance 1905 and part 1906) . .		227 1 11	
— Conversazione		937 6 9	
			2,930 14 4
— Salaries		3,350 0 0	
— Clerks, Messengers, and Housekeeper		1,594 5 8	
— Retiring Allowances and Donations		1,686 0 0	
			6,630 5 8
— Library:—Books and Periodicals		306 9 0	
Binding		354 18 5	
			661 7 5
Carried forward			£14,088 15 1

ABSTRACT *of* RECEIPTS *and* EXPENDITU

RECEIPTS—*continued.*

Dr.	£	s.	d.	£	s.	£	s.
Brought forward						33,156	15
To Engineering Standards Committee :—							
Balance of Funds at 31 March, 1905, transferred to the Institution in accordance with agreement dated 20 June, 1905				1,816	1 1		
— Received from Board of Trade in respect of Grant :—							
Account of 1904–5	50	0	0				
„ „ 1905–6	1,500	0	0				
„ „ 1906–7	500	0	0				
				2,050	0 0		
— Subscriptions				1,226	15 0		
— Amount received from Committee on account of Sale of its Publications				916	17 7		
— Interest on Deposit				15	19 2		
				6,025	12 10		
Deduct Payments to the Engineering Standards Committee				4,700	0 0		
— Balance in hand 31 March, 1906						1,325	12

CAPITAL.

	£	s.	d.	£	s.
To Admission-Fees	3,117	9	0		
— Life-Compositions	215	5	0		
				3,332	14

TRUST FUNDS.

Telford Fund.

To Dividends :—1 year on

£	s.	d		£	s.	d.	£	s.
5,439	11	0	$2\frac{1}{2}$% Consols	129	3	8		
3,299	2	0	Ditto (Unexpended Dividends)	78	7	4		
			Refund of Income Tax, to 5 Apl. 1905	10	18	4		
£8,738	13	0						
			Carried forward	£218	9	4	£37,815	2

from the 1ST APRIL, 1905, *to the* 31ST MARCH, 1906.

EXPENDITURE—*continued.*

Cr.	£	s.	d.	£	s.	d.
Brought forward				14,088	15	1
By Publications :—						
"Minutes of Proceedings," Vols. clx, clxi, clxii, and Vol. clxiii	6,849	12	0			
Charters, By-Laws, and Lists of Members . .	206	17	11			
				7,056	9	11
— Professional Auditor's Fee	105	0	0			
— Legal Expenses	64	4	5			
— Examinations	912	13	0			
— Donation to Westminster Hospital	10	10	0			
— Contribution to the Expenses of the National Physical Laboratory	500	0	0			
— Standing Committee Expenses	7	7	0			
				1,599	14	5
				22,744	19	5

CAPITAL.

	£	s.	d.	£	s.	d.
By Purchase of £5,400 London County 3% Stock .	5,025	8	6			
— Plans *re* Proposed New Building	105	0	0			
				5,130	8	6

TRUST FUNDS.

	£	s.	d.	£	s.	d.
By Telford Premiums :—						
Balance 1903–4	51	7	3			
1904–5	177	16	3			
— Telford Medals	45	5	0			
Carried forward . .	£274	8	6	£27,875		11

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

Dr.	RECEIPTS—*continued.*	£ s. d.	£ s. d.	£ s. d.
	Brought forward . .		218 9 4	37,815 2 7
	TRUST FUNDS—*continued.*			
	Manby Donation.	£ s. d.		
£250 0 0	Great Eastern Ry. 4% Irredeemable Guaranteed Stock	9 10 0		
	Refund Income Tax . .	9 10		
			9 19 10	
	Miller Fund.			
3,125 0 0	2½% Consols	74 4 8		
2,004 17 5	Ditto (Unexpended Dividends)	47 12 4		
	Refund Income Tax . .	6 8 0		
£5,129 17 5			128 5 0	
	Howard Bequest.			
£551 14 6	2½% Consols	13 2 0		
	Refund Income Tax . .	13 8		
			13 15 8	
	Trevithick Memorial.			
£103 0 0	2½% Consols	2 9 0		
	Refund Income Tax . .	2 8		
			2 11 8	
	Crampton Bequest.			
£512 15 11	2½% Consols	12 3 4		
	Refund Income Tax . .	13 0		
			12 16 4	
	"James Forrest" Lecture and Medal Fund.			
£372 0 0	South-Eastern Ry. 5% Debenture Stock . . .	17 13 4		
	Refund Income Tax . .	18 3		
			18 11 7	
	Palmer Scholarship.			
1,381 1 6	Metropolitan 3% Stock .	39 7 4		
115 4 7	Ditto (Unexpended Dividends)	3 5 8		
£1,496 6 1	Refund Income Tax . .	2 4 8		
			44 17 8	
	John Bayliss Bequest.			
£1,013 17 10	London County 3% Stock	28 18 0		
	Refund Income Tax . .	1 10 4		
			30 8 4	
	Yarrow Educational Fund.			
6,728 0 0	Midland Ry. 2½% Preference Stock . . .	159 15 10		
4,220 0 0	North Eastern Ry. 4% Preference Stock . .	160 7 2		
	Refund Income Tax . .	8 8 6		
			328 11 6	
£10,948 0 0				808 6 11
				£38,623 9 6

from the 1ST APRIL, 1905, *to the* 31ST MARCH, 1906.

	£	s.	d.	£	s.	d.	£	s.	d.
EXPENDITURE—*continued.*									
Cr. Brought forward				274	8	6	27,875	7	11
TRUST FUNDS—*continued.*									
By Manby Premium				9	13	0			
— Miller Prizes	80	12	6						
— Miller Scholarship	40	0	0						
				120	12	6			
— Crampton Prize				10	2	6			
— "James Forrest" Lecture (thirteenth)	15	17	4						
— James Forrest Medal	2	15	0						
				18	12	4			
— Palmer Scholarship— 1 year's dividend, etc., to Scholar				44	17	8			
— Baylis Prizes				30	0	0			
— Yarrow Educational Fund				38	12	0			
							546	18	6
							28,422	6	5
— Balance, 31 March, 1906, viz. :—									
On Deposit				6,000	0	0			
Cash in the hands of the Treasurer :—									
Current Account				2,413	17	7			
No. 2 „				461	3	10			
Engineering Standards Committee Account				1,325	12	10			
Cash in the hands of the Secretary					8	10			
							10,201	3	1
							£38,623	9	6

STATEMENT OF INVESTMENTS HELD 31 MARCH, 1906.

Institution Investments.

£			£	s.	d.	£	s.	d.
10,000	2½% Consols	Cost	9,286	17	1			
9,400	London County 3% Stock	"	9,025	9	6			
4,000	Manchester Corporation 3% Stock	"	4,085	1	0			
6,000	Metropolitan 3½% Stock	"	6,517	15	0			
3,000	Metropolitan Water Board 3% Stock	"	2,958	16	0			
6,000	Great Eastern Railway 4% Debenture Stock	"	7,749	18	3			
8,000	Great Northern Railway 3% Debenture Stock	"	7,642	16	4			
8,000	Great Western Railway 4% Debenture Stock	"	10,547	5	0			
8,000	Lancashire and Yorkshire Railway 3% Debenture Stock	"	7,452	14	8			
7,300	London and North Western Railway 3% Debenture Stock	"	6,792	10	5			
9,600	Midland Railway 2½% Debenture Stock	"	7,460	18	11			
79,300						79,520	2	2
	Original cost of the freehold of the Institution Premises and of the New Building, including buildings now removed					124,379	10	0

Note.—No value has been attached, for the purpose of this statement, to the Books, Furniture, Fittings, Pictures, &c., in the Institution Building.

Trust Funds Investments.

Telford Fund.

£	s.	d.			£	s.	d.
1,945	19	0	2½% Consols	—Acquired with a bequest of	2,000	0	0
3,479	12	9	do.	Converted from Government Stocks bequeathed	Bequest.		
13	19	3	do.	Purchased with bonus on conversion cost	13	11	3
5,439	11	0					
3,299	2	0	do.	Purchased with unexpended dividends	3,034	18	1
8,738	13	0					

Manby Donation.

£	s.	d.		
250	0	0	Great Eastern Railway 4% Irredeemable Guaranteed Stock	Donation.

Miller Fund.

£	s.	d.			£	s.	d.
3,125	0	0	2½% Consols	—Acquired with a bequest of	3,000	0	0
2,004	17	5	do.	Purchased with unexpended dividends	1,850	2	4
5,129	17	5					

TRUST FUNDS INVESTMENTS—*continued.*

Howard Bequest.

£	s.	d.		£	s.	d.
551	14	6	2½% Consols—Acquired with a bequest of . . .	500	0	0

Trevithick Memorial.

103	0	0	2½% Consols—Acquired with a presentation of . .	100	0	9

Crampton Bequest.

512	15	11	2½% Consols—Acquired with a bequest of . . .	500	0	0

"James Forrest" Lecture and Medal Fund.

320	0	0	South Eastern Railway 5% Debenture Stock Acquired with a subscription of	510	0	0
52	0	0	Ditto Acquired with a subscription of £93 14*s.* 8*d.* and 19*s.* 4*d.* cash	94	14	0
372	0	0				

Palmer Scholarship.

1,381	1	6	Metropolitan 3% Stock bequeathed	Bequest.		
115	4	7	Ditto purchased with unexpended dividends . .	132	18	0
1,496	6	1				

John Bayliss Bequest.

1,013	17	10	London County 3% Stock Acquired with a bequest of	1,000	0	0

Yarrow Educational Fund.

6,728	0	0	Midland Railway 2½% Preference Stock	10,049	9	6
4,220	0	0	North Eastern Railway 4% ditto . . . . (Acquired with a gift of £10,000 and £49 9*s.* 6*d.* interest thereon.)			
10,948	0	0				

J. H. T. TUDSBERY, *Secretary.*

9 *April*, 1906.

Examined with the Books and Securities and found correct.

PERCIVAL D. GRIFFITHS, F.C.A.
JAMES M. DOBSON } *Auditors.*

APPENDIXES.

APPENDIX I.

YARROW EDUCATIONAL FUND.

The Institution of Civil Engineers, having accepted from Mr. Alfred Fernande: Yarrow the capital sum of £10,000 in trust to apply the income thereof i accordance with the wishes of the donor—as expressed in his letters to the Counci of the 10th March and the 11th June, 1904, and the 24th January, 1906—toward the training of young men who, desiring to become engineers, lack sufficient means to obtain the necessary scientific and practical knowledge, have adopted the following rules for guidance in selecting persons to receive assistance from the Fund :—

I.—Candidates must be British subjects, and not more than 21 years of age.

II.—The Fund is intended, primarily, to assist Candidates who have entered the engineering section of an approved technical college; and who have during their course of study at college been regular in attendance, and given evidence of earnestness of character and exceptional ability. Candidates who have, during a course of practical training, evinced the same qualities, and who wish to continue their training by a college course, will also be assisted. Other things being equal, preference will be given to Candidates who have obtained Scholarships or Exhibitions, or other educational distinctions.

III.—Evidence must be forthcoming that each Candidate cannot provide the means to continue his engineering education either from his own resources or with the aid of friends or relatives.

IV.—The authorities of technical colleges and representative engineers will be requested periodically to submit names of Candidates, who comply with the above conditions, to the Council of The Institution of Civil Engineers.

V.—Candidates who receive instructions to that effect must attend at The Institution of Civil Engineers (their expenses being defrayed), and appear before a Committee, who will report to the Council of The Institution the names of those whom they consider most suitable for assistance from the Fund.

VI.—The grants of money made in each case will be assigned by the Committee of Selection, and will generally vary from £50 to £100 per annum, for not more than three years.

VII.—Successful Candidates must undertake to enter as Students or Associate Members of The Institution of Civil Engineers.

VIII.—Grants from the Fund will be known as "Yarrow Scholarships."

APPENDIX II.

List of Pictures in the Possession of The Institution of Civil Engineers.

Revised on the basis of the List appended to the Council Report of 2 June, 1896.

Subject.	Born.	Died.	President.	How Acquired.	Painter.
Telford, Thomas .	1757	1834	1820–34	Bequeathed .	S. Lane.
Ditto (Copy) .	"	"	"	Painted for The Institution .	W. M. Palin, after S. Lane.
Walker, James .	1781	1862	1835–45	" "	J. P. Knight, R.A.
Rennie, Sir John .	1794	1874	1845–48	" "	James Andrews.
Field, Joshua . .	1786	1863	1848–50	" "	James Andrews.
Cubitt, Sir William	1785	1861	1850–52	Presented by Jos. Cubitt, V.P. . . .	Sir W. Boxall, R.A.
Simpson, James .	1799	1869	1854–56	Presented by his sons . . .	Replica, Sir W. Boxall, R.A.
Stephenson, Robert, M.P. .	1803	1859	1856–58	Painted for The Institution .	Henry Phillips.
Ditto (Study for Britannia Bridge group) . . .	"	"	"	Purchased by The Institution	J. Lucas.
Ditto (Full length Portrait) . . .	"	"	"	Presented by George and T. St. L. Stephenson .	J. Lucas.
Locke, Joseph, M.P.	1805	1860	1858–60	Bequeathed by Mrs. Locke .	Sir Francis Grant, P.R.A.
Bidder, George Parker . . .	1806	1878	1860–62	Purchased by The Institution	Unknown.
Hawkshaw, Sir John	1811	1891	1862–64	Presented by himself . .	T. Collins.
M'Clean, John Robinson, M.P.	1813	1873	1864–66	Presented by his son . . .	Charles Landseer, R.A.
Fowler, Sir John, Bart., K.C.M.G.	1817	1898	1866–68	Presented by members .	Sir John Millais, P.R.A.
Gregory, Sir Chas. Hutton, K.C.M.G.	1817	1898	1868–70	" "	Hon. John Collier.
Vignoles, Charles Blacker . . .	1793	1875	1870–72	..	Mrs. Croudace.
Hawksley, Thomas	1807	1893	1872–74	Presented by members .	H. Herkomer, R.A.

LIST OF PICTURES—*continued.*

Subject.	Born.	Died.	President.	How Acquired.	Painter.
Harrison, Thomas Elliot . . .	1808	1888	1874–76	Painted for The Institution .	Replica, W. W. Ouless, R.A.
Bateman, J. F. Latrobe . . .	1810	1889	1878–80	Hon. R. C. Parsons, M. Inst. C.E. . . .	Clegg Wilkinson.
Barlow, William Henry, F.R.S. .	1812	1902	1880	Bequeathed. .	Hon. John Collier.
Abernethy, James .	1814	1896	1881	Presented by his sons . . .	W. M. Palin.
Armstrong, Lord .	1810	1900	1881–82	Presented by himself . .	Mrs. M. L. Waller.
Bazalgette, Sir J. W., C.B. . .	1819	1891	1884	Presented by Lady Bazalgette . . .	Replica—Ossani.
Bramwell, Sir Frederick, Bart.	1818	1903	1885–86	Presented by members .	Frank Holl, R.A.
Woods, Edward .	1814	1903	1886–87	Presented by himself . .	Miss Porter.
Bruce, Sir George Barclay . . .	1821	..	1887–89	Presented by members .	W. M. Palin.
Coode, Sir John, K.C.M.G. . .	1816	1892	1889–91	Presented by his son . . .	Clegg Wilkinson.
Hayter, Harrison .	1825	1898	1892–93	Presented by himself . .	J. C. Michie.
Rawlinson, Sir Robert, K.C.B. . .	1810	1898	1894–95	,, ,,	Phil Morris, A.R.A.
Baker, Sir Benjamin, K.C.B. .	1840	..	1895–96	,, ,,	J. C. Michie.
Barry, Sir J. Wolfe, K.C.B. . . .	1836	..	1896–98	,, ,,	W. M. Palin.
Preece, Sir Wm., K.C.B. . . .	1834	..	1898–99	,, ,,	Miss B. Bright.
Fox, Sir Douglas .	1840	..	1899–1900	,, ,,	W. M. Palin.
Mansergh, James, F.R.S. . . .	1834	1905	1900–01	,, ,,	,, ,,
Hawksley, Charles	1839	..	1901–02	,, ,,	Sir George Reid.
Hawkshaw, John Clarke, M.A. .	1841	..	1902–03	,, ,,	Hon. John Collier.
Molesworth, Sir Guilford L., K.C.I.E. . .	1828	..	1904–05	,, ,,	Miss B. Bright.

LIST OF PICTURES—*continued.*

Subject.	Born.	Died.	How Acquired.	Painter.
Myddelton, Sir Hugh .	1555	1631	Presented by Charles Greaves, M. Inst. C.E. .	After Cornelius Jansen.
Brunel, Isambard Kingdom, Vice-President .	1806	1859	Presented by his sons	J. C. Horsley, R.A.
Miller, Joseph, Member of Council	1797	1860	Painted for The Institution . .	Sir W. Boxall, R.A.
Siemens, Sir William, Member of Council .	1823	1883	Presented by Lady Siemens . .	Rudolf Lehmann.
Brassey, Thomas . . .	1805	1870	Presented by H. P. Burt, Assoc. Inst. C.E. . .	J. B. Hallé.
Wilson, General Alexander	1776	1866	Presented by his family . . .	Unknown.
Manby, Charles, Secretary	1803	1884	Presented by T. R. Crampton, M. Inst. C.E. .	Sidney Hodges.
Forrest, James, Secretary	1825	..	Presented by the Council . . .	W. M. Palin.
Boulton, Matthew . .	1728	1809	Presented by George Rennie	Unknown.
Brindley, James . . .	1716	1772	Presented by Sir John Hawkshaw, Past-President .	F. Parsons.
Huddart, Joseph . . .	1740	1816	Presented by James Walker, Past-President	Wildman, after Hoppner.
Jessop, William . . .	1745	1813	Presented by his son	Edwin Williams.
Rennie, John (senior) .	1761	1821	Presented by Sir John Rennie, Past-President	Raeburn.
Stephenson, George . .	1781	1848	Presented by George Robert Stephenson, Past-President	J. Lucas.
Ditto (Full length Portrait)	"	"	Presented by George and T. St. L. Stevenson	J. Lucas.
Stephenson, George and Robert	..	..	Purchased by The Institution . .	J. Lucas.
Smeaton, John . . .	1724	1792	Presented by Alfred Burges, M. Inst. C.E. .	Wildman, after Gainsborough.
Whidbey, Joseph . .	..	1833	Presented by George Rennie, M. Inst. C.E. .	J. Ponsford.
Bidder, George Parker, as a child (the "calculating boy"). (Pres. Inst. C.E. 1860–2) .	1806	1878	Presented by John Nelson and members of his family . .	Unknown.

LIST OF PICTURES—*continued.*

Subject.	Born.	Died.	How Acquired.	Painter.
Conference of Engineers at the Britannia Bridge (portraits of leading members of the profession in 1850) . .	..	..	Presented by George Robert Stephenson, Past-President	J. Lucas.
Brunel, Sir Marc Isambard	1769	1849	Presented by Mrs. Saxton Noble . . .	Copy by W. C. Horsley, from the original portrait by James Northcote, R. A.
Abel, Sir Frederick . .	1827	1902	Presented by himself . . .	Frank Bramley, A.R.A.
Ashwell, James, M.A. .	1799	1881	Bequeathed by Mrs. Mary Ashwell	Guglielmo de Sancti.
King Charles I., Children of	..	..	..	Oldstone, after Vandyck.
Menai Bridge	..	..	Bequeathed by Telford . . .	..
Pont-y-Cysylte Aqueduct	..	..		..
Old Westminster Bridge.	..	..	Presented by R. Price-Williams, M. Inst. C.E. .	Samuel Scott.
Grimsby Docks . . .	..	..	Bequeathed by Mrs. Rendel .	J. W. Carmichael.
Woolwich Dry Dock, 1841	..	..	..	..
Hanwell Viaduct, 1837 .	..	..	..	..
Water Colour Drawing, made in 1863, of "Construction of Westminster Bridge" . . .	..	..	..	Rienzi G. Walton, M. Inst. C.E.

EDUCATION AND TRAINING OF ENGINEERS.

Report of a Committee appointed by the Council of The Institution of Civil Engineers on the 24th November, 1903.

Members of the Committee:

Sir WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S., *Chairman.*

ARCHIBALD BARR, D.Sc.
Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S.
Sir ALEXANDER R. BINNIE.
ALEXANDER GRACIE.
ROBERT KAYE GRAY.
HARRY E. JONES.
Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S.
HENRY LOUIS, M.A.
A. T. TANNETT-WALKER.
R. L. WEIGHTON, M.A.
J. HARTLEY WICKSTEED.

WE have the honour to submit the following Report and Recommendations for the consideration of the Council of The Institution of Civil Engineers, in accordance with the terms of Reference to this Committee, which was appointed—

> "To consider and report . . . . as to the best methods of training for all classes of Engineers, including both scholastic and subsequent technical education; it being an instruction to this Committee that the principle shall be maintained that the education of an Engineer must include both practical experience and scientific training."

It is desirable to place on record, at the outset, a brief account of the circumstances under which the Committee was appointed, by unanimous Resolution of the Council, on the 24th November, 1903.

In taking this action the Council of The Institution of Civil Engineers proceeded on lines which had been followed for a long period, with a view to improvement in the training and status of Civil Engineers.

An exhaustive inquiry had been made in 1868 into then existing

conditions and systems of engineering education in the United Kingdom and in foreign countries; and the results of this inquiry were published by The Institution in 1870. In 1891 another statement was published dealing fully with the facilities for Engineering education afforded at that date by the Engineering schools of Universities and Colleges in the British Dominions.

The educational qualifications required of candidates for admission as Students in 1889, and subsequently the system of examinations established in 1897 for Students and Associate Members of The Institution of Civil Engineers, furnished further proof of the importance attached by the Council to the higher education of Civil Engineers.

During the year 1903 renewed discussions of this subject took place at the Engineering Conference of The Institution of Civil Engineers, and at meetings of The Institution of Mechanical Engineers, The Institution of Naval Architects, and important Engineering Societies outside London. These discussions showed wide differences of opinion as to the best methods of training engineers, but indicated a general feeling in favour of thorough investigation of the subject by some body representing all branches of engineering, whose conclusions would command the attention of all who were interested in the education and training of engineers. This general desire was definitely expressed in a letter (of 8th May, 1903) addressed by the President of The Institution of Mechanical Engineers to the President of The Institution of Civil Engineers, stating that the Council of the former Society considered it desirable that a representative Committee should be appointed by the Council of The Institution of Civil Engineers to consider and report on the whole subject of engineering education. This suggestion was the immediate cause of action by the Council of The Institution of Civil Engineers (November 1903) after the summer vacation, when steps were taken to appoint the Committee whose work is now completed.

The Council then decided to request the Engineering Societies named below to assist the proposed Inquiry by nominating representatives to serve thereon:—

The Institution of Mechanical Engineers.
The Institution of Naval Architects.
The Iron and Steel Institute.
The Institution of Electrical Engineers.
The Institution of Gas Engineers.
The Institution of Engineers and Shipbuilders in Scotland.
The Institution of Mining Engineers.
The North-East Coast Institution of Engineers and Shipbuilders.

All these Institutions complied with the request, and nominated representatives, and the constitution of the Committee was completed in February, 1904, as under:—

Sir WILLIAM H. WHITE, K.C.B., D.Sc., LL.D., F.R.S., Past-President Inst. C.E., *Chairman.*

The PRESIDENT of The Institution of Civil Engineers (*ex-officio*).

Sir JOHN WOLFE BARRY, K.C.B., LL.D., F.R.S., Past-President Inst. C.E.

Sir ALEXANDER B. W. KENNEDY, LL.D., F.R.S., Vice-President Inst. C.E.

J. HARTLEY WICKSTEED, M. Inst. C.E. (*representing The Institution of Mechanical Engineers*).

ALEXANDER GRACIE, M. Inst. C.E. (*representing The Institution of Naval Architects*).

Sir EDWARD H. CARBUTT, Bart.,[1] M. Inst. C.E. (*representing the Iron and Steel Institute*).

R. KAYE GRAY, M. Inst. C.E. (*representing The Institution of Electrical Engineers*).

HARRY E. JONES, M. Inst. C.E. (*representing The Institution of Gas Engineers*).

Prof. ARCHIBALD BARR, D.Sc., M. Inst. C.E. (*representing The Institution of Engineers and Shipbuilders in Scotland*).

Prof. HENRY LOUIS, M.A. (*representing The Institution of Mining Engineers*).

Prof. R. L. WEIGHTON, M.A. (*representing the North-East Coast Institution of Engineers and Shipbuilders*).

J. H. T. TUDSBERY, D.Sc., M. Inst. C.E., *Secretary.*

J. G. HENDERSON, B.Sc., Assoc. M. Inst. C.E., *Assistant-Secretary.*

As the members of the Committee were busily occupied and widely scattered over the country, it was felt from the first that much of the work must be done by correspondence, and that it would be advantageous before meetings took place to settle the heads under which the inquiry might be arranged most conveniently. For that purpose the following memorandum was prepared and circulated by the Chairman to the members of the Committee.

[1] On the regretted death of Sir Edward Carbutt, in October 1905, Mr. A. T. Tannett-Walker, M. Inst. C.E., was appointed to serve on the Committee as a representative of the Iron and Steel Institute.

Proposed Sections of Inquiry.

1. *Preparatory Education in Secondary Schools;* with special reference to suitable training of youths who are intended for the Engineering profession in Mathematics, Elementary Science, Modern Languages and Handicrafts.
2. *Training in Offices, Workshops, Factories, or on Works;* including the decision as to the period or periods at which such training can best be given, its character and duration. The possibility to be considered of giving to the preliminary stages of this practical training as broad a character as possible, so as to prepare students for any branch of engineering they may subsequently enter.
3. *Training in Universities and Higher Technical Institutions.*
   Opinions to be formed as to:—
   (*a*) The most suitable age at which average students could begin this course.
   (*b*) The possibility of arranging the earlier courses of study so as to be common to all branches of engineering.
   (*c*) The duration of such common courses of study.
   (*d*) The extent to which specialization should be provided for in technical institutions, and the extent to which it should be carried.
4. *Post-graduate Work.* How it can best be organized and maintained:—
   (*a*) At Universities and Higher Technical Institutions.
   (*b*) On actual works, and in mines, factories, etc.

At the first meeting of the Committee (held on the 24th February, 1904) this memorandum was approved, and it was decided to entrust detailed consideration of the first section (Preparatory Education in Secondary Schools) to a sub-Committee consisting of Sir Alexander Kennedy (Chairman), Professors Archibald Barr, Henry Louis, and R. L. Weighton, and Mr. Alexander Gracie. It was further agreed that the Committee, as a whole, should undertake the consideration of (*a*) Practical training in offices, workshops, factories, or on works; and (*b*) Training in Universities and higher technical Institutions.

In prosecuting their inquiries the Committee thought it essential to obtain, either orally or in writing, the opinions of persons having experience in engineering education, and of eminent engineers practising in various branches of the profession. It was desired to

make this record of opinion precise, representative and comprehensive; for which purpose members of the Committee undertook to suggest the form in which inquiries should be framed, to give the names of those to whom application might be made, and to indicate general detailed action, which, in their judgment, would be of value in the collection of opinions and information. These suggestions were summarized and condensed, under the supervision of the Chairman, by the Secretary and Assistant-Secretary. The Schedules of Questions approved by the Committee and subsequently issued were prepared on this basis.

These preliminaries necessarily occupied a considerable time and entailed a large amount of correspondence. Their final result has been the attainment of both definiteness and wide range in the questions circulated; and has secured the collection of a great body of opinion from representative engineers in active practice, professors and teachers in Technical Colleges and Universities, and others whose advice has been of value in reaching a decision on matters referred to the Committee. The scope of their inquiry was necessarily extensive, and the Committee desire to express their gratitude to the large number of gentlemen who have favoured them with advice and opinions. They recognize that those who have given assistance are actively engaged in educational and professional work, which made it no easy matter to devote attention to the questions asked. On the other hand, the numerous and full responses made by men whose experience gives authority to their opinions and recommendations, have enabled the Committee to proceed with greater certainty in framing their Report. Diversities of opinion have been disclosed in regard to some details, as was inevitable from the nature of the subjects: but in all main features of their recommendations the Committee have support from the large majority of their professional colleagues and of the teachers in Universities and higher technical Institutions. This fact cannot fail to carry great weight with those for whose benefit the Report has been prepared.

The Committee are of opinion that it would not have been possible in any other way to have secured equally full consideration of the subject, or so valuable a mass of information and opinion in regard to the principles it is desirable to follow in training engineers. More time and labour have been involved by adopting the method of written communication instead of oral evidence; but a much larger number of men has been reached, and the final result is more satisfactory.

I. Inquiry as to Preparatory Education. (*See Appendix I.*)

The details of this portion of their work were entrusted by the Committee to the above-mentioned sub-Committee. A schedule of the questions issued by the sub-Committee will be found in Appendix I, which also contains an analyzed summary of the replies. This Schedule was issued to 120 representatives of the following classes:—

(1) Teachers in Engineering Colleges.
(2) Headmasters of Secondary Schools at which it is believed special attention is paid to scientific training.
(3) Engineers not engaged in teaching.

Replies were received from 80 per cent. of the gentlemen whose opinions were invited; and from these replies definite conclusions were deduced as to the prevalent opinions on points raised by the questions.

The Report which the sub-Committee submitted to the main Committee was considered at a meeting held on the 23rd March, 1905, and was then approved and adopted.

The following are accordingly the recommendations of the Committee in respect of the most suitable preparatory education for boys who are intended to become engineers.

RECOMMENDATIONS IN RESPECT OF PREPARATORY EDUCATION.

1. It is desirable that a boy intended for the Engineering Profession should, before leaving school and commencing to specialize, have attained a standard of education equivalent to that required by the Institution Studentship Examinations; and that he should not commence his special training until he is about 17 years of age.

2. A leaving examination for secondary schools, similar in character to those already existing in Scotland and in Wales, is desirable throughout the United Kingdom. It is desirable to have a standard such that it could be accepted by The Institution as equivalent to the Studentship Examination, and by the Universities and Colleges as equivalent to a Matriculation Examination.

3. Advanced teaching of History and Geography, with instruction and practice in Essay-writing and in Précis-writing, should be included in the ordinary school curriculum; and the instruction in

English subjects should include at least an introduction to English Literature.

4. Greek should not be required, but an elementary knowledge of Latin is desirable. The study of Latin should, however, be discontinued during the last two years of attendance at school, or after the standard required for the leaving certificate has been attained. Modern languages, especially French and German, should be studied, and should be taught colloquially or in such a way as to give the pupils a practical knowledge of each language, sufficient to enable them to study its literature and to converse in it with some degree of facility.

5. Instruction in Mathematics should be given by methods differing considerably from those usually adopted in the teaching of this subject merely as an intellectual exercise. The geometrical side of Mathematics should be fostered, and before they leave school boys should be conversant with the use of logarithms, and with at least the elements of trigonometry, including the solution of triangles. It is also of importance that instruction in practical arithmetic should be carried further than has been generally the case hitherto, with the object especially of encouraging the use of contracted methods and operations in mental arithmetic; and of encouraging also the expression of results with only such a degree of (numerical) precision as is consistent with the known degree of certainty of the data on which they are or may be supposed to be based.

6. It is preferable that boys should attain at school a general knowledge of elementary Physics and Chemistry, or of what is sometimes called "Natural Philosophy," rather than that they should pursue in detail some particular department of science.

7. Special attention should be given to drawing; the instruction should include ordinary Geometrical Drawing with orthographic projection, Curve-drawing, Freehand Drawing, and Practical Mensuration.

8. Work in the nature of handicraft, such as Carpentry or Turning, or elementary field-surveying, may be encouraged as a recreation but should not be required as a school exercise.

9. It appears to be impossible, in the general curriculum of school work, to include advantageously time for instruction in such a subject as Surveying, which has been suggested.

The Committee recommend that this scheme of Preparatory Education should be officially communicated to the Board of Education and widely circulated amongst those engaged in the conduct of Secondary Schools and Engineering Colleges, in order that future schemes of tuition of youths who contemplate entry into

the Engineering profession may be guided thereby. The Committee are of opinion that if this course is taken it would assist in overcoming one great difficulty now universally felt in Institutions in which applied science is taught. At present a considerable proportion of students enter technical institutions ill-prepared, and at least one year has to be devoted to instruction which ought to be secured beforehand. Proper preparation is essential if students are to derive full benefit from special instruction in applied science. Professors and teachers ought not to be required to undertake subjects that should be taught elsewhere, but should be left free to devote themselves to scientific and technical instruction, which is their real work.

II. Inquiry as to Engineering Training. (*See Appendix II.*)

The Committee found it convenient to deal with Sections 2, 3 and 4 of the inquiry together. These include Training in Offices, Workshops, Factories or on Works, generally designated "practical" training: Training in Universities and Higher Technical Institutions: and Post-Graduate Work. In these instances also, as explained above, a schedule of questions was framed (Appendix II) and was circulated widely; but the Committee embodied in the Schedule their conclusions on certain important subjects which had been thoroughly discussed by the members, and on which they were unanimous. In that course there was no interference with the free expression, by those whose opinions were solicited, of views contrary to those of the Committee; and the replies indicated clearly that this fact was realized. Nor were the comments of correspondents limited to points raised in the schedule. On the contrary, perfectly independent statements of opinion were submitted in many cases. The Committee desired primarily to ascertain the views of men whose opinions were entitled to respectful consideration, in consequence of their experience and study of education and of Engineering training. In all instances these communications have received due consideration by the Committee, after being carefully grouped and analyzed.

Each member of the Committee was at liberty to forward the names of gentlemen to whom schedules should be sent, and each Institution was asked officially to suggest names, in order that the list might be made as complete as possible, and that each department of Engineering might be adequately represented. The total number of schedules issued was 676, and the total number of replies received was 267.

Their distribution over different branches of the profession may be classified roughly as follows:—

—	No. of Schedules issued.	No. of Replies received.
1. Engineers engaged in constructional work (railways, docks, harbours, canals, waterworks, sewerage, etc.)	34	16
2. Mechanical engineers	200	82
3. Mining engineers	72	22
4. Iron and steel manufacturers	47	16
5. Naval architects, shipbuilders and marine engineers	119	32
6. Gas engineers	94	39
7. Electrical engineers	66	30
8. Professors, and others who are, or have been, engaged in teaching	44	30
	676	267

The gentlemen whose opinions were asked were actively engaged in professional work, and in consequence there were delays in making replies. Repeated applications were necessary before the inquiry could be completed, and it was decided finally to make the 1st November, 1905, the latest date for the receipt of replies.

An analysis of the replies is given in Appendix II. From this it will be seen that the tentative suggestions and recommendations embodied by the Committee in their Schedule have received very general support; this support has been given by each of the great sections of the Engineering profession. A few correspondents expressed radically different views; but, in the main, the opinions of the Committee have been endorsed, and this result is satisfactory, since it indicates the possibility of practical effect being given to the recommendations. The Committee were not assisted so fully by replies to their question on mathematical teaching as to others; they therefore obtained specially the opinions of their colleagues engaged in tuition, and of other gentlemen who have large experience in this matter.

The Committee have had in view throughout what may be termed an "average boy," of ordinary ability, whose parents are in a position to secure for him a thorough training before he begins his actual professional work as an engineer. They recognize the necessity that will always exist for providing also suitable means of training for young men not so favourably situated, who work their way by sheer ability and force of character, and whose earlier careers do not permit of the methodic preparatory education and training which they consider best for the average boy. The Committee also recognize the

certainty that other most valuable recruits for the Engineering profession will continue to enter at a later period of life, and from other systems of education and employment. At the same time, it is obvious that, in all such cases, men may be trusted to find their way, and to avail themselves of existing opportunities for instruction and training. Their concern, therefore, has been with the best general scheme adapted to the average boy.

The Committee have not overlooked the established customs of Universities and Colleges to which Engineering Schools are attached, and have given weight to the necessity for arranging terms and courses of study with due regard to general efficiency in the conduct of these Institutions. Consequently they do not recommend absolute uniformity of arrangement in College courses of study or in their method of association with practical training; nor do they consider such uniformity necessary. In Scotland, it may be anticipated that the alternation of winter study at the Universities with long summer vacations, usually spent in practical work, will be continued; whereas in England the sessions and vacations will be arranged differently. Other varieties of practice exist or will be introduced; and, in the judgment of the Committee, considerable latitude is permissible in these matters without loss of educational efficiency.

RECOMMENDATIONS IN RESPECT OF ENGINEERING TRAINING.

The Committee desire to preface these recommendations by the statement that they are unanimous in the opinion that engineering training must include several years of practical work, as well as a proper academic training. Long experience has led to general agreement amongst engineers as to the general lines on which practical training should proceed; and it has, therefore, been unnecessary to deal at any great length with that matter in the recommendations. It must not be supposed, however, that the fuller treatment of academic training in the following pages indicates its greater relative importance; the reason for this fuller treatment is to be found rather in a desire to suggest courses of study which can be best associated with the practical training that is essential to engineering education.

Taking the Schedule of opinions and questions relating to practical training (Appendix II) as determining the order followed, the Committee make the following Recommendations. The numbers refer to the sections of Appendix II.

1. The average boy should leave school when he is about 17 years of age. Much depends upon the development of individual boys, but the minimum age should be 16 and the maximum 18 years.

2. The practical training should be divided into two parts, whenever that arrangement can be made; and the preliminary stage of practical training should consist in all cases of at least a year spent in mechanical engineering workshops. This "introductory workshop course" is desirable even when students do not contemplate devoting themselves at a later stage to what is generally designated "mechanical engineering." Thus, for mining engineers, the machine-shops of a large colliery would be found especially suitable. The Committee are supported in this recommendation by the opinions expressed by a large proportion of the engineers who have been consulted. It is recognized that at present there are practical difficulties in arranging for this workshop year being interposed between the school and college work, and that employers may consider the arrangement objectionable in their interests. On the other hand, the Committee suggest that these difficulties should not be insurmountable; and the general agreement as to its advantageous effect on training leads them to hope that practical trial may be given to the suggestion. In any case, the Committee recommend that an "introductory workshop course" of at least a year should be included whenever possible in the practical training of all engineering students. Where the "introductory workshop course" is possible before the College training, it should not be less than one year, nor more than two years. The longer period may be desirable in the case of boys who are to become mechanical engineers, and useful in all cases when boys leave school at 16 years. In some cases it may be preferred to take the workshop course after the first year of the College training common to all branches of Engineering. An interruption of College training at a later period must involve great disadvantages.

3. During workshop training boys should keep the regular working hours, should be treated like ordinary apprentices, be subject to discipline and be paid wages.

4. Nothing should be done in the form of evening study which would impose undue strain upon the physique of boys. In some cases this might prevent attendance at evening classes; but experience shows that many boys can attend such classes without physical injury and with great educational advantage. The Committee think it is most important that all boys should at least maintain their scholastic acquirements during the introductory workshop course, and, for the class of boys in question, it is considered that this result might be secured, by private tuition or otherwise, without undue physical strain.

Nothing should be done to discourage boys, who so desire and are physically fit, from adding to their knowledge either by private study or by attendance at classes.

5. As a rule it is preferable to proceed to a Technical College or University on the completion of the introductory workshop course. This is advantageous to most boys, as it abridges the period between School and College, and lessens the danger of retrogression in knowledge. It also facilitates the arrangement of common courses of study for junior students in technical Colleges and Universities; and, on the whole, gives the students better opportunities of benefiting by College training.

In some cases—as for example when boys are intended to become mechanical engineers—it may be advantageous to complete the practical training before entering College; but, if this is done, it becomes more important that simultaneous education during practical training should be secured by private tuition or in evening classes; otherwise boys would lose seriously during four or five years' suspension of systematic study, and would be disadvantaged on entering College.

The alternation of College Study and practical training is only feasible when (as in the Scotch Universities) the College vacation practically occupies half the year; or in the case of mining engineers, where the official requirements under the Coal Mines Regulation Acts prescribe a minimum period of 4 months spent in mines before the termination of the College course.

6. For the average student the period of College study should be three sessions, provided he is well prepared before entering College. In the case of students who desire to follow up the science of their profession a fourth year might be added, which would be in some cases post-graduate work, and might come after the practical training is completed. In cases where students are exceptionally well-prepared before entering College, or are above the ordinary age, or possibly without the means required for a full course of study, facilities should be given for shortening the course of study.

In all cases the first Session might be advantageously devoted to a common course of study by average students, and probably that common course might be extended into the second Session without loss to final specialization.

7. A sound and extensive knowledge of Mathematics is necessary in all branches of Engineering, although some of these branches require more advanced mathematics in their practice than others. The capacity for acquiring mathematical knowledge varies greatly in individual students, and many who become competent Engineers

have not the power of acquiring the higher mathematics. These differences of actual requirements and individual capacity must be recognized in courses of instruction, and can hardly be dealt with by any general statement.

It should be possible, however, for the student of average ability who, at his entry upon the study of applied science, has advanced to the stage of preparation in mathematics outlined in the foregoing recommendation as to preparatory training (see p. 165) to master sufficiently during the common course of instruction for all engineering students the subjects included under the category of pure mathematics; provided the instruction proceeds in a systematic and well-considered manner.

The Committee endorse the practically universal recommendation, made by those whose special knowledge and experience entitle them to speak with authority, that a sufficient time should be allotted to the study of pure mathematics during the common college-course, to permit the best students to obtain a sound knowledge of Algebra, Trigonometry, Analytical and Practical Plane Geometry, the elements of Solid Geometry, and a working knowledge of the Differential and Integral Calculus, and of the simpler Differential Equations. To this fundamental mathematical training there must be added instruction in Applied Mathematics and Mechanics. The extent to which individual students can be carried in this course must be a matter left to the discretion of the teaching staff, whose means of observation and power of assessing the capability of individual students can alone decide the matter. In the judgment of the Committee, it is most important that, when teachers consider that individual students are lacking in the power of proceeding successfully with their higher mathematical studies, time should not be wasted in persevering therewith. On the other hand, many students of this class under proper instruction are capable of benefiting greatly by well-considered courses of instruction in the practical applications of mathematics.

In the later terms of the college course of study, time devoted to purely mathematical instruction should be lessened as compared with the time similarly devoted during the earlier terms; and that given to specialized instruction in engineering subjects should be increased. The most advantageous arrangement, both for students and teachers, will consist in the combination of mathematical and engineering instruction by the professors and teachers of engineering. The teachers of pure mathematics also, in dealing with the students during their common course of study, should be well-informed as to the applications of mathematics in engineering, so

that their courses of instruction may be arranged suitably, and that departments of these subjects having no bearing upon engineering may not have given to them unnecessary time or attention.

With regard to the teaching of geometrical drawing, physics, chemistry, and geology, the existing arrangements of the Universities and Technical Colleges appear to be satisfactory and to meet all cases.

Without interference with the organization of individual colleges, it would be found in the highest degree beneficial to arrange conferences between the staffs of all the important teaching institutions; so that a uniformly high standard of qualification on the part of students, at the completion of their courses of study, may be maintained.

8. At least three to four years should be spent in practical training, inclusive of the "introductory workshop course" previously mentioned. The Committee favour a total period of four years' practical training where it can be secured: this being carried out in workshops, on works, in mines and in offices, as may be required in each case. It is highly desirable that a part of this practical training should be obtained in drawing-offices.

9. Where College training is completed before practical training is taken, the total period devoted to the latter should be three years in ordinary cases. Exceptional ability may justify a somewhat shorter period. The hours of work should be the same as if the usual course were followed: the wages paid should be somewhat higher, especially in the later years. The Committee make this general recommendation whilst recognizing that this is not the practice in mining.

10. The Committee recommend strongly efficient instruction in Engineering drawing.

Instruction in testing materials and structures, and in the principles underlying metallurgical processes and other practical operations incidental to the branch of engineering in which a student proposes to specialize, should be included in the College course.

In regard to workshop practice in technical colleges, they are of opinion that boys who have spent one or two years in mechanical engineering workshops should not be instructed in workshop practice at technical colleges.

11. In connection with the grant of degrees, diplomas and certificates to engineering students, considerable importance should be attached to laboratory and experimental work performed by individual students, as well as to their progress in mathematical and scientific studies; and degrees, etc., should not be granted on the

results of terminal or final examinations alone. Practical unanimity is shown in regard to this procedure by those whose opinions were obtained, and it is considered to be of great importance in assessing the professional attainment of students.

12. Facilities for, and organization of, post-graduate work by engineering students in Universities and Higher Technical Institutions should be considerably increased. This recommendation is made with the special object of encouraging qualified students to undertake researches which may prove of practical value to engineering operations and processes. The number of such students is not likely to be large at any time, but their influence on younger students should be highly beneficial, and the advantage to engineering and industry should be considerable. In many cases the best period for post-graduate work would be that following the completion of practical training, even when that training follows the College course.

13. The Committee reaffirm the conviction expressed when they issued their inquiry, that the sympathetic assistance of employers is essential to improvement in engineering education and training.

In conclusion, the Committee desire to express their indebtedness to the Secretary (Dr. Tudsbery) and the Assistant-Secretary (Mr. Henderson) for the valuable and unwearied assistance which they have rendered throughout the inquiry, and would repeat their acknowledgment of indebtedness to all those who have assisted with opinions and information.

W. H. WHITE,
Chairman of the Committee.

J. H. T. TUDSBERY,
Secretary.

7 *April*, 1906.

[APPENDIXES.

APPENDIXES.

APPENDIX I.

SCHEDULE OF QUESTIONS RELATING TO PREPARATORY EDUCATION AND TRAINING OF ENGINEERS, ISSUED BY THE SUB-COMMITTEE; WITH A SUMMARY OF THE REPLIES RECEIVED.

QUESTION.	SUMMARY OF REPLIES.	
		Per Cent.
1. What is the proper age for leaving school, having in view the fact that the boy has ahead of him a practical and theoretical training which will cover certainly 4, probably 5, and perhaps 6 years before he can become a regular Assistant in any branch of Engineering work?	Average age recommended—	
	Less than sixteen	4·5
	Sixteen	19·0
	Between sixteen and seventeen	14·0
	Seventeen	40·0
	Between seventeen and eighteen	4·5
	Eighteen	10·0
	Exceeding eighteen	8·0
		100·0
		Per Cent.
2. (a) What is your view as to the desirability of a leaving examination for Secondary Schools?	(a) Desirable	90·0
	Undesirable	10·0
		100·0
(b) If such an examination is possible or desirable, should it be in the hands of the school itself or of external examiners, or of both conjointly?	(b) School itself	5·0
	External Examiners	41·0
	Both conjointly	54·0
		100·0
(c) Could it, and, if so, should it be utilized as the equivalent of a Matriculation or Entrance Examination for the various Colleges giving education to Engineers?	(c) Yes	93·5
	Doubtful	6·5
		100·0
3. English Subjects.		Per Cent.
(a) Is it possible to develop further than has generally been the case hitherto, the teaching of History and Geography in what may be called their commercial aspects?	(a) Yes	85·5
	Not desirable	14·5
		100·0
(b) Could Précis Writing be included under this heading?	(b) In favour	84·0
	Doubtful or not in favour	16·0
		100·0
(c) Can anything be done to give extended instruction and exercise in Essay Writing?	(c) In favour	88·0
	Doubtful or not in favour	12·0
		100·0

APPENDIX I.—*continued.*

QUESTION.	SUMMARY OF REPLIES.
4. Languages. (a) How far is it desirable that boys definitely intended for the Engineering profession should continue the study of the classical languages, or of either of them, until the time when they leave school?	Per Cent. (a) In favour . . . . 47 Recommend discontinuance at least 2 years earlier . . 41 Recommend omission of classics altogether 12 100
(b) If it is thought that the study of these subjects ought to be continued to the end, what amount of time should be spent upon them during the last two years?	(b) About 5 or 6 hours a week . 77 About 10 hours a week . . 23 100 The replies to (a) and (b) refer, in the majority of cases, to Latin alone, the general opinion being that Greek may be either omitted entirely or discontinued at an earlier stage.
(c) To what extent can **Modern Languages**—especially French and German—be taught colloquially or in such fashion as to make them really useful, without the expenditure of unnecessary time on theoretical grammatical exercises or in the study of classical comedies?	Per Cent. (c) Approve of this method . . 77 Doubtful or not in favour . 23 100 In many cases residence abroad is recommended as the only means of acquiring a real colloquial knowledge of modern languages.
5. Mathematics. (a) Can general mathematical teaching be given to boys who intend to become Engineers in such a way as to help them later on in the practical use of mathematics—such a method of teaching naturally differing much from the method which would be used if mathematics were to be merely an intellectual exercise, not actually employed later on in real life, nor even used for the sake of passing an examination? (It has to be remembered that in the great majority of cases the boys whose natural bent is towards engineering find the geometrical side of mathematics fairly easy, but have difficulties with its analytical side. It is considered desirable also that boys leaving school for Engineering training should have more than the mere minimum represented by four Books of Euclid, etc. They ought certainly to know something about Logarithms and the elements of Trigonometry, and also about Similar Figures. It is thought that ample opportunity for such teaching could be found by the omission of the matters mentioned in (5) below.)	Per Cent. (a) In favour . . . . 85 Not in favour 15 100

APPENDIX I.—*continued.*

QUESTION.	SUMMARY OF REPLIES.	Per Cen
5. Mathematics—*continued.* (*b*) Is it desirable that the teaching of Mathematics at School should be arranged with a view to attain all or any of the following objects?—	(*b*)	
1. The practical use of arithmetic with the special object of obtaining correct results independently of the mere study of arithmetical methods.	1. Yes No	8 1 10
2. The encouragement of the use of contracted methods.	2. Yes No	91 9 10
3. The encouragement of exercises in mental arithmetic.	3. Yes No	94 6 100
4. The teaching, at this stage, of what Prof. Perry has called "Practical Mathematics," of the use of Logarithms, of Elementary Trigonometry (limited, for example, to right-angled triangles), of the general ideas of Projective Geometry, including points and lines at infinity, and the use of the slide-rule.	4. Yes No Omit slide-rule	85 10 5 100
5. The elimination from instruction in Mathematics of such matters as Cube Root Extraction and elaborate Algebraic Equations, which are purely intellectual gymnastics without any direct usefulness.	5. Yes No	90 10 100
6. Science.		Per Cent.
(*a*) Is it better that boys should be made superficially familiar with the general language and ideas of Elementary Physics and Chemistry, or that they should be carried somewhat further in one particular section of such work?	(*a*) Recommend former " latter " both conjointly	67 23 10 100
(*b*) Would it be advisable rather to encourage the general study of what used to be known as "Natural Philosophy" as a subject of general mental training as well as of practical interest? (It has been a matter of common complaint among Engineering Professors that in many cases the mechanical ideas imbibed by schoolboys have done more harm than good in their subsequent study of the subject. If, however, it	(*b*) Yes No	78 22 100

APPENDIX I.—*continued.*

QUESTION.	SUMMARY OF REPLIES.
6. Science—*continued.* were possible to give schoolboys a thorough grounding in the elements of Mechanics, it would, of course, be useful.) (*c*) In view of the results hitherto obtained, would it be well to omit Theoretical Mechanics altogether from school teaching.	Per Cent. (*c*) Yes . . . . 77 No 23 100
7. Practical Work. (*a*) How far has it been found desirable that schoolboys should have, as a school exercise, practice in ordinary handicraft work, such as Carpentry or Turning?	Per Cent. (*a*) Undesirable as a school exercise 44 Desirable . . . . 38 Desirable in some cases, or to a limited extent . . . 18 100 In many cases it is recommended that the boys should be encouraged to take up handicraft work, as a recreation, out of school hours.
(*b*) To what extent has it been found better and more useful, to make the "practical" work really into Laboratory Exercises or Experiments, whether Physical, Chemical or Mechanical?	Per Cent. (*b*) Consider it desirable and practicable . . . . . . 38 Consider it desirable . . . 42 Do not recommend this method 20 100
8. Drawing. What are your views as to the following schemes of instruction in Drawing to be taught in school to boys who are going afterwards into Engineering?	Per Cent.
(*a*) The ordinary teaching of Geometrical Drawing with orthographic projection, including especially curve drawing, both by co-ordinates and by purely projective methods.	(*a*) Desirable . . . . 92 Undesirable 8 100
(*b*) Free-hand Drawing from ordinary drawing-class models or from solids representing simple details of an engineering character.	(*b*) Desirable . . . . 96 Undesirable 4 100
(*c*) The drawing, in orthographic projection, of objects from actual measurement, a subject which has been called Practical Mensuration.	(*c*) Desirable . . . . 83 Undesirable 17 100
9. Surveying. Is it desirable, and, if so, is it possible, to include anything like instruction in simple chain surveying, without optical instruments, for boys during their school period?	Per Cent. Undesirable . . . . 53 Possible and desirable . . . 31 Desirable 16 100

APPENDIX II.

SCHEDULE OF OPINIONS AND QUESTIONS RELATING TO TRAINING IN OFFICES, WORKSHOPS, FACTORIES, OR ON WORKS; AND IN TECHNICAL COLLEGES AND UNIVERSITIES; WITH A SUMMARY OF THE REPLIES RECEIVED.

Comments and replies are invited upon the following opinions and questions. In making them it is requested that answers be given with special reference to boys of average ability, who are destined for the Engineering Profession and who have sufficient means to go through a full course of training.

Alternative suggestions will be welcomed and will receive full consideration.

OPINION OR QUESTION.	SUMMARY OF REPLIES.	Per Cent.
1. The Committee are of opinion that the age for leaving school should be about 17 years.	Agree	70
	Prefer Sixteen	17
	Prefer Eighteen	7
	Prefer Fifteen	4
	Other replies	2
		100
2. (a) The Committee are of opinion that it is desirable that the course of training for all branches of Engineering should include at least one year's training in Mechanical Engineering workshops, where, ordinarily, information would be gained of the practical applications of electricity. (This is referred to hereafter as the "*introductory workshop course*.")	(a) Agree	72
	One year too short	21
	Do not agree	4
	Other replies	3
		100
(b) The Committee think that this introductory workshop course should be taken at an early period—either previously to the commencement of College training, or after that portion of the College training which is common to all branches of Engineering (*see* 6 below) has been completed.	(b) Agree	33
	Before college	47
	After common portion	10
	Complete college first	5
	Alternating with college	3
	Other replies	2
		100

APPENDIX II.—*continued.*

OPINION OR QUESTION.	SUMMARY OF REPLIES.
3. The Committee are of opinion that during this (and any subsequent) course of training in workshops, boys should keep the regular working hours, including early morning attendance, and should be treated like ordinary apprentices, and be paid wages.	Per Cent. Agree . . . . 79 Do not agree entirely . . . . . 8 Shorter hours if attending evening classes . . . . 7 Should not be paid wages . . . 5 Other replies 1 100
4. Is it desirable, having regard to the age and physical development of the boys— (*a*) To require them to attend classes for evening study during this introductory workshop course; or, (*b*) That this period should be devoted entirely to practical work—ordinary educational work being meanwhile suspended?	Per Cent. (*a*) and (*b*) Former preferable . . . . . . 55 Latter preferable . . . . 35 Former, with shorter working hours 3 Depends on individuals . . . . 2 Other replies 5 100
5. Assuming such an introductory workshop course to be approved for all boys, is it recommended— (*a*) That it should be followed by a period of study in a technical college or University before specialization in particular branches of engineering is undertaken; or, (*b*) Is it considered preferable that this workshop course should be at once followed by a period of practical training in the branch of engineering for which the boy is intended; or, (*c*) Is it deemed desirable that the period of College study should be arranged so as to alternate with the workshop or other practical training—and, if so, in what manner	Per Cent. (*a*) and (*b*) Former preferable . . . . . . 64 Latter preferable . . . . 31 Other replies . . . . 5 100 (*c*) Desirable . . . . 63 Undesirable . . . . 29 Difficult to arrange . . . . . . 5 Desirable in some cases . . . . 1 Other replies . . . . 2 100 Of those who consider the course indicated in (*c*) desirable, 42 per cent. recommend attendance at college during the winter 6 months, and at the workshop during the summer 6 months, in each year.

APPENDIX II.—*continued.*

OPINION OR QUESTION.	SUMMARY OF REPLIES.	(a)	(b)
		Per Cent.	Per Cent.
6. The Committee are of opinion that the earlier course of College study should be arranged so as to be common to all branches of engineering. This being assumed— (a) How long a period should be assigned to such common course of study? (b) What is a reasonable total period of College study for a boy of average ability?	One session	38	2
	One or two sessions	6	..
	Two sessions	42	15
	Two or three sessions	2	7
	Three sessions	5	51
	Three or four sessions	1	9
	Four sessions	2	11
	Four or five sessions	..	1
	Five sessions	..	1
	Other replies	4	3
		100	100

OPINION OR QUESTION.	SUMMARY OF REPLIES.	(a)	(b)	(c)	(d)	(e)
		Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent
7. To what extent should College study be carried, in (a) Mathematics? (b) Geometrical Drawing? (c) Physics? (d) Chemistry? (e) Geology?	Recommend standards comparable with that of B.Sc. (in Engineering) of London University	54	10	11	8	7
	The more the better	23	23	27	18	15
	Advanced instruction	13	32	28	23	12
	Elementary instruction	..	17	18	18	34
	Should be taught with regard to its application in engineering	..	9	..	2	5
	Include laboratory	..	..	6	20	..
	Should be optional	..	..	..	..	15
	Other replies	10	9	10	11	12
		100	100	100	100	100

OPINION OR QUESTION.	SUMMARY OF REPLIES.	Per Cent.
8. Apart from the introductory workshop course, what is considered to be a reasonable total period of practical training on works, in factories, workshops, mines, etc., when the age of specialization is reached?	One year	4
	One to two years	3
	Two years	21
	Two to three years	11
	Three years	31
	Three to four years	5
	Four years	8
	Four to five years	1
	Five years	4
	Over 5 years	3
	Other replies	9
		100

APPENDIX II.—*continued.*

OPINION OR QUESTION.	COMMENT OR ANSWER.

9. In cases where boys complete their College training before beginning their practical training, what is thought best —considering that they must now be about 21 years of age—

(*a*) In regard to the introductory workshop course?

(*b*) In regard to the period required for specialization in particular branches of engineering?

(*c*) In regard to hours of work and payment of wages in workshops, drawing-offices, mines, works, etc., during such period of specialization?

	(*a*)	(*b*)	(*c*)
	Per Cent.	Per Cent.	Per Cent.
Same as if taken earlier	33	33	76
May be shortened .	4	1	..
Should be omitted .	26	..	..
One year	19	5	..
Eighteen months .	2	3	..
Two years . . .	5	17	..
Two to three years .	..	5	..
Three years . . .	3	19	..
Four years . . .	..	4	..
Until proficient . .	..	2	..
Wages should be higher	..	..	10
Other replies .	8	11	14
	100	100	100

Would your suggestions in the foregoing respects differ, and, if so, to what extent in cases where practical training preceded or alternated with the College course?

With only a few exceptions, the replies to this question are all in the negative.

Entire disapproval of the course referred to in (9) is expressed in more than 50 per cent. of the replies.

10. Is it desirable to provide, and, if so, on what scale, in technical colleges, appliances and equipment for instructing students in—

(*a*) Engineering drawing?

(*b*) Workshop practice?

(*c*) Testing materials or structures?

(*d*) Metallurgical processes?

(*e*) Other practical operations incidental to engineering works?

	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Yes; in general, scale to be limited only by the funds at disposal	80	48	86	69	71
No	6	36	2	10	13
Doubtful . . .	..	..	..	6	2
On small scale only	..	9	..	9	..
Moderate equipment	..	..	8	..	..
In some colleges .	..	..	..	2	..
To teach principles .	6	3	..	..	7
To illustrate lectures	2	2	1	1	2
Include principles of design	3	..	..	..	..
Other replies .	3	2	3	3	
	100	100	100	100	100

APPENDIX II.—*continued.*

OPINION OR QUESTION.	COMMENT OR ANSWER.	Per Cent.
11. The Committee are of opinion that it is desirable, in connection with the grant of degrees, diplomas and certificates to engineering students, that considerable importance should be attached to laboratory and experimental work performed by individual students, as well as to their progress in mathematical and scientific studies, rather than that degrees, etc., should be granted on the results of terminal or final examinations alone.	Agree	91
	Not too much importance	2
	Already being done	2
	Reports from Works also desirable	2
	Other replies	3
		100
12. The Committee are of opinion that facilities for, and organization of, post-graduate work by engineering students in higher technical institutions should be considerably increased.	Agree	83
	Do not agree	5
	Scholarships required	2
	By specially qualified students only	3
	Difficult to attract the best men	1
	Other replies	6
		100
13. The Committee are of opinion that the improvement of Engineering Education depends greatly on the attitude of employers towards the suggestions foreshadowed in this memorandum; and the Committee would especially urge upon employers the importance of extending facilities to Engineering students for the prosecution of post-graduate work.	Agree	74
	Do not agree	4
	Employers willing to grant facilities	7
	Students must show themselves capable	4
	Difficulties in the way	3
	Other replies	8
		100

MEDALS AND PREMIUMS AWARDED FOR THE SESSION 1904–1905, AND PRESENTED ON THE 7TH NOVEMBER, 1905.

FOR PAPERS READ AND DISCUSSED AT THE ORDINARY MEETINGS.

1. A Telford Gold Medal to Lord Brassey, K.C.B., D.C.L., Assoc. Inst. C.E., for his Paper entitled "Shipbuilding for the Navy."
2. A Telford Gold Medal to Charles Stuart Russell Palmer, M. Inst. C.E., for his Paper on "Coolgardie Water-Supply."
3. A Watt Gold Medal to John Francis Cleverton Snell, M. Inst. C.E., for his Paper on "Distribution of Electrical Energy."
4. A George Stephenson Gold Medal to Lyonel Edwin Clark, M. Inst. C.E., for his Paper on "Floating Docks."
5. A Telford Premium to William Marriott,[3, 5] M. Inst. C.E., for his Paper entitled "The Maintenance and Strengthening of Early Iron Bridges."
6. A Telford Premium to Richard William Allen, Assoc. M. Inst. C.E., for his Paper on "Surface-Condensing Plants, and the Value of the Vacuum Produced."
7. A Telford Premium to Leveson Francis Vernon-Harcourt,[1, 2, 3, 4] M.A., M. Inst. C.E., for his Paper on "The River Hooghly."
8. A Crampton Prize to Arthur Wood-Hill, Assoc. M. Inst. C.E., and a Manby Premium to Edward Davy Pain, B.A., Stud. Inst. C.E., for their joint Paper on "The Construction of a Concrete Railway-Viaduct."

[1] Has previously received a Telford Medal.
[2] Has previously received a George Stephenson Medal.
[3] Has previously received a Telford Premium.
[4] Has previously received a Manby Premium.
[5] Has previously received a Miller Prize.

For Papers Printed in Section II. of the Proceedings for the Session 1904–1905.

1. A George Stephenson Gold Medal to Matthew Henry Phineas Riall Sankey,[1, 3] *Capt.* R.E. *ret.*, M. Inst. C.E.,
   A Watt Gold Medal to Charles Chree, M.A., D.Sc., LL.D., F.R.S., and
   A Telford Premium to William Ernest Wyatt Millington, Stud. Inst. C.E., for their joint Paper on the "Strength of Shafts subject to small Forces rhythmically applied."
2. A Telford Premium to Johann Philip Edmond Charles Stromeyer,[1, 3] M. Inst. C.E., for his Paper on "The Gauging of Streams by Chemical Means."
3. A Telford Premium to Claude William Hill, Assoc. M. Inst. C.E., for his Paper on "Electric Cranes."
4. A Telford Premium to Frederick Charles Lea, B.Sc., Assoc. M. Inst. C.E., for his Paper on "The Determination of the Stresses in Lattice-Girder Bridges when subject to Concentrated Travelling Loads, and the Effect of Replacing these Loads by Equivalent Loads."
5. A Telford Premium to William Bartholomew Cole, M. Inst. C.E., for his Paper on "The Widening of London Bridge."
6. A Telford Premium to William Charles Popplewell, M.Sc., Assoc. M. Inst. C.E., for his Paper on "Some Experiments for Determining the Elastic and Ultimate Strength of Brick-work Piers and Pillars of Portland Cement Concrete."
7. Telford Premiums to Edward Hulme Rigby, B.Sc., and William Orr Leitch, Jun.,[5] Assoc. MM. Inst. C.E., for their joint Paper on "Railway Construction in North China."

For Papers Read before Meetings of Students in London and at the Provincial Associations.

1. A Miller Prize and the "James Forrest" Medal to Alfred Bertrand Potts, Stud. Inst. C.E. (Manchester Association), for his Paper on "Street Railways."
2. A Miller Prize to William Muir Hayman, Stud. Inst. C.E. (Glasgow Association), for his Paper on "Reconstruction of the Pierhead Quay Wall at Troon Harbour."

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[1] Has previously received a Telford Medal.
[3] Has previously received a Telford Premium.
[5] Has previously received a Miller Prize.

3. A Miller Prize to Ronald Edward Bury, Stud. Inst. C.E. (Manchester Association), for his Paper on "Drop Forging."
4. A Miller Prize to Thomas Lees, Jun., Stud. Inst. C.E. (Glasgow Association), for his Paper on "Permanent Way."
5. A Miller Prize to Thomas Leigh Matthews, Stud. Inst. C.E. (London), for his Paper on "Concrete-Making on the Admiralty Harbour Works, Dover."
6. A Miller Prize to Philip James Risdon, Stud. Inst. C.E. (London), for his Paper on "Destruction and Reconstruction of the Santa Lucia River Bridge (Uruguay)."
7. A Miller Prize to Frederic Edward Tudor, Stud. Inst. C.E. (Yorkshire Association), for his Paper on "Some Notes on Organ Construction."

Bayliss Prize.

Bayliss Prizes, awarded on the results of the October and February Examinations 1904–1905 respectively, to William Foulis and Ronald Bugler Aries, Studs. Inst. C.E.

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN 1 APRIL, 1905, AND 31 MARCH, 1906.

AUTHORS.

Abernethy, G. N. No. 3,635.—The Midland Railway Company's Harbour at Heysham, Lancs. With 5 Drawings and 2 Tracings. (Vol. clxvi.)

Appleyard, R. No. 3,603.—Measurement of Electrical Conductivity of Short Rods. With 1 Drawing. (Vol. clxiv.)

Baldwin-Wiseman, W. R. No. 3,574.—The Puddling Effect of Water flowing under steady pressure through Concrete. With 1 Tracing. (Vol. clxiii.)

————————. No. 3,594.—The Flow of Underground Water. With 15 Tables, 7 Tracings and 2 Photographs. (Vol. clxv.)

Barnaby, S. W. No. 3,632.—Note on the Cavitation of Screw Propellers. (Vol. clxv.)

Barnett, M. R. No. 3,636.—Repairing Limestone Concrete Aqueduct. With 1 Drawing, 5 Tracings, and an Album of Photographs.

Bingham, P. M. No. 3,610.—Automatic Registration and Weighing of Vehicular Traffic in Ceylon. With 3 Tracings.

Blackwall, J. E. No. 3,604.—Country Roads for Modern Traffic. With 1 Drawing. (Vol. clxv.)

Blagden, H. R. C. No. 3,615.—Description of the New Filtration Works for supplying the town of Alexandria with Potable Water. With 9 Tracings. (Vol. clxvi.)

Boycott, G. W. M. No. 3,609.—Caisson Disease at the New High Level Bridge, Newcastle-on-Tyne. With 1 Diagram. (Vol. clxv.)

Braine, C. D. H. No. 3,584.—Method of Calculating Areas of Earthworks, Excavations and Embankments, without plotting the cross-sections. With 1 Sheet of Diagrams.

Burn, W. No. 3,569.—Sutton-in-Ashfield Sewerage.

Butler, D. B. No. 3,625.—The Specific Gravity of Portland Cement. (Vol. clxvi.)

Cole, H. A. B. No. 3,591.—Some Notes on the Towing Resistance of Floating Docks. With 1 Diagram. (Vol. clxiv.)

Collins, M. R. No. 3,622.—Irrigation in the Transvaal. With 3 Drawings. (Vol. clxv.)

AUTHORS.

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Zimmer, G. F. No. 3,568.—The Mechanical Handling of Hot Coke. With 3 Drawings and 2 Tracings. (Vol. clxiii.)

EXTRA MEETING.

2 May, 1906.

Sir ALEXANDER RICHARDSON BINNIE, President, in the Chair.

THE "JAMES FORREST" LECTURE, 1906.

THE PRESIDENT said that it was his pleasing duty to introduce the lecturer, Mr. R. A. Hadfield, who, he was sure, required no words of commendation from him. He, therefore, without further preface, called upon Mr. Hadfield to deliver the lecture which he had so kindly promised.

The following lecture was then delivered:—

"Unsolved Problems in Metallurgy."

By ROBERT ABBOTT HADFIELD, M. Inst. C.E.

PART I.

PROBLEMS OF METALLURGY.

To be requested to undertake this, the fourteenth "James Forrest" Lecture, is an honour I greatly appreciate. I ask your indulgence for shortcomings in its preparation, as the work has been carried out amidst pressure of official business in connection with another Institution. But whatever calls there may be on our time we all recognize that the claim of our Alma Mater is great. This I personally feel, being indebted to our Institution for the generous encouragement given to my researches by the acceptance of a Paper contributed in 1888.

I shall, too, ever remember Mr. Forrest's kindness to me when I became a member of this Institution, and the assistance he so freely rendered when my Paper was read, the first of a technical nature I had then prepared. His cheery encouragement in what, at the

time, seemed to me a heavy labour was of the greatest help, and the hand of friendship has, I know, been as freely held out by him to others. All honour to him for the good work he has done, and for his lifelong devotion to the interests of this great Institution, whose branches spread throughout the world. By the kind permission of the Council, the report of this lecture which will appear in the "Proceedings" will be accompanied by a portrait of Mr. Forrest.

It would be difficult to enumerate the names of the many friends whose generous assistance has been afforded to me in the course of my experimental researches. I take, however, this opportunity of thanking the Nestor of our Institution, Sir George Barclay Bruce, for his kindness to me in 1888, when he occupied the Presidential Chair. I would also thank Sir Alexander Kennedy, who has done so much for our Institution; his name stands for accuracy in the highest and best sense of the term. It was to him I went in the year 1887 with the products of some of my early experiments and found him engaged in his mechanical testing-laboratory at University College. Testing-laboratories were in those days few and far between, but he was able to smooth away the many difficulties encountered in making tests with the intractable material I handed him. Busy as he was, he at once expressed great interest in my experiments, and the results of his important tests are duly recorded in the "Proceedings" of this Institution. Let me add that his kindly assistance set me again to work, greatly encouraged for future researches. I mention these facts to show how much friendly assistance is of value to younger men.

A lecture of this kind has its happy prerogatives; there is no discussion, and the lecturer is afforded a free hand. But this great freedom brings greater responsibility. It behoves me, therefore, to tread carefully, and if my Address appears to deal not so much with general subjects as with a special one, this is for the simple reason that the specialized subject I have chosen—Metallurgy—is the only one which I can venture to put before you.

The "James Forrest" Lecture has been given by many men of genius and sterling worth: Anderson, who in 1893 was the first to undertake the duty, Hopkinson and Roberts-Austen—these, alas! no longer with us—besides others happily still living. In the shadow of these great intellects I recognized the responsibility I was asked to undertake, and hesitated to accept it; but our President, and also Sir William White, who himself has done so much to help metallurgists by presiding over the Alloys Research Committee of the Institution of Mechanical Engineers, would hear of no refusal, and overcame my reluctance.

In any case, I ask that my contribution may not be taken so much as a lecture, but rather as a plain, and, I hope, practical talk upon the matters to which my life has been chiefly devoted. Let it be added that it has been undertaken mainly with the object of helping our younger members. The word "help" is here used in the broadest sense. I certainly do not pretend to teach, but rather hope to inspire interest from the records of my own experience.

Mr. Forrest was good enough to give me a topic for this lecture— that of "Unsolved Problems of Engineering." As already intimated, my remarks will be confined as strictly as possible to problems relating to my own profession, that of metallurgy, and I shall deal chiefly with iron and its alloys.

Research.

Let me first deal briefly with the general subject of research, and indicate how problems of Metallurgy should be approached.

This is an age of research, but in recapitulating victories do we not often overlook how much remains to be done?

It was recently remarked, by one eminent in medical science, that whilst we have made great advances, how much there is to learn! If, therefore, instead of priding ourselves on the gigantic strides we have made, some courageous President would devote an address to a few of those things in which gigantic strides have not been made, it might form a stronger incentive to progress.

Lord Bacon, speaking of scientific knowledge and the advantages of research, has said, "It is a pleasure to stand upon the shore, and to see ships tost upon the sea: a pleasure to stand in the window of a castle and to see a battle and the adventures thereof below; but no pleasure is comparable to the standing on the vantage ground of truth (a hill not to be commanded, and where the air is always calm and serene), and to see the errors and wanderings, and mists and tempests, in the vale below: so always that this prospect be with pity and not with swelling or pride."

As shown by Gore in his admirable treatise, "The Art of Scientific Discovery," all really true and valuable research-work on unsolved problems must be proceeded with on systematic, not on haphazard lines. To Students of this Institution I strongly commend the perusal of Gore's book. It is a treasure-house of great suggestions, and so full of wisdom that I have drawn freely from it.

Scientific research, as Gore points out, is not supernatural. The younger members of our Institution, whatever may be their special field of activity, need not hesitate to undertake such work through

fear of difficulties to be encountered, nor feel apprehensive of repeating experiments which others have made, nor refrain because they fear they do not know how to select suitable subjects for research. The ground is always ready to be broken; no field of scientific inquiry has ever been exhausted.

It is an essential condition of success in research that the investigator should be free from bias in favour of old views, and open-minded for the reception of new ones. No prejudiced person can be a good investigator, for prejudice misleads the senses when observing results, and hampers judgment when interpreting phenomena. Original research needs independent thought. Science ignores mere authority, and requires in its stead reasonable evidence; it demands also the sacrifice of personal pride, and that its study should be approached with true humility.

Dwelling on the need for truth, Gore points out that trustworthiness is the first object of science, and accuracy its final aim. These terms are not, as many may think, synonymous, for trustworthiness represents a logical idea only, or one matter of fact, accuracy a quantitative conclusion. We may say that it is more important to be trustworthy than to be accurate, because the former affects the fact itself, the latter only its degree or relative quantity. Priestley may be said to have been an example of a chemist who was trustworthy but not accurate. He was a great qualitative investigator; he discovered many new substances, and, as subsequent experience has proved, his discoveries were real; but his experiments were crude in a quantitative sense, he rarely made use of the balance, and he was unable to make quantitative analyses.

Priestley, although he made important advances in chemistry, could not bring his mind to admit the doctrine of the general principle of oxidation. He discovered in 1774 that oxygen could be separated from oxide of mercury; this he did by means of a burning-glass. He called it dephlogisticated air, but it was left to Lavoisier to study and understand the properties of this element. The sterility of this great discovery in Priestley's hands was due partly to his blind adherence to Stahl's phlogiston theory, and partly to the carelessness of his own experiments. To err in this way is the lot not only of men in general, but of men of great endowments and sincere love of truth.

Herschel has said regarding the development of science, that the greatest worker in science can do no more than accelerate the progress of discovery. Great ideas often germinate in obscurity until the time comes for proving their truth; the hour and the man for each new discovery.

That Newton's great discovery would soon have been made appears quite probable when we consider the knowledge arrived at by previous investigators. This in no way detracts from the grandeur of his work, and is an aspect that should humble all.

Buffon considered that scientific genius is only protracted patience; Cuvier, that in the exact sciences at least it is the patience of a sound intellect, when invincible, which truly constitutes genius, and infinite patience is the truly scientific spirit. Helvetius thought that genius is nothing but continued attention; Lord Chesterfield, that the power of applying the attention steadily and undissipatedly to a single object is a sure mark of a superior genius. Surely these maxims by great men of the past should be of encouragement to the younger members of this Institution. They suggest nothing insuperable, only that you should choose your line of action and keep to it steadily.

Metallurgy.

As a metallurgist I can safely claim that this particular branch of engineering comes under the aim of our charter, "The application and direction of the great sources of power in nature to the use and service of man," and I trust I am not biassed in saying that the labours of the metallurgists are of the highest importance. Whilst fully recognizing the good work done in the many branches of engineering, it must be allowed that without the aid of metallurgy none of the great structural and mechanical achievements of to-day could have been called into existence. Who has used the metallurgist's productions to greater advantage than our Past-President, Sir Benjamin Baker, in that marvellous masterpiece of metals—the Forth Bridge?

The syllabus of our Institution shows how considerable is the interest taken by the Council in the work of the metallurgist, for of the 104 suggested Subjects for Papers, about 21 per cent. relate directly to metallurgical science. If those subjects indirectly concerned with metallurgy be included, the proportion is brought to nearly 50 per cent. Let us take subject No. 4 as an instance—"The increase of speed in express travelling." Here metallurgical advance has had to precede that of mechanical design. At the time George Stephenson applied his inventive genius to the inception of mechanical traction, the locomotive as we know it to-day could not have been constructed, because the materials now supplied by the metallurgist were then unknown. Incidentally it may be mentioned that America in 1905 spent no less than £52,000,000 sterling on locomotives and rolling-stock, chiefly composed of iron and steel.

The pure metal, iron, has a tensile strength of about 19 tons per square inch, yet by the metallurgist's art in preparing alloys, and by thermal and mechanical treatment, this tenacity can be increased nearly ten times, whilst there are a thousand and one intermediate states. It is upon a correct application of these facts that modern progress has been based. If we take away the metal iron and its alloys we return to the dark ages.

The Tools of the Metallurgists.—Let us consider some of the many problems of metallurgy still remaining to be solved. These, as I have said, are my theme, but in dealing with them I am no necromancer, neither shall I attempt to treat them exhaustively, as, indeed, it is quite impossible to do in a brief lecture such as the present. I will indicate only some amongst many, and, like the explorer who takes with him charts, maps, and the equipment likely to be most useful, I shall, this evening, try to show you some of the instruments or tools of the metallurgist, by the aid of which he has solved, or partially solved, some of the difficulties encountered in the past, and by which he may hope to continue his work in the future.

Practical Demonstrations.—In the ordinary way a lecturer on a scientific subject explains and illustrates his theme as he proceeds, but to an audience such as I have the honour of addressing, and with a subject like the present, this method seems to me to have defects. Though engineers are engaged in the application of metallurgical products, many are not concerned in the actual work of the metallurgist, and to carry out during the reading of this Paper all the experiments to which reference will presently be made would be tedious, even if it were possible. Much of the apparatus needed could not be shown in this hall, and it is here that a chemist or physicist would have an advantage in addressing you. A lecture-theatre can be quickly turned into a lecture-laboratory, but metallurgical demonstrations need greater space and a more permanent installation of apparatus.

There is another reason why I have formed my lecture on a somewhat unusual mould. For a subject of a technical nature more time is needed for lucid explanation than is generally at command, and in these "James Forrest" Lectures the audience is denied opportunity for asking questions. Therefore it may be that many present would have but vague ideas about matters upon which they would desire to be well-informed.

Taking these points into consideration, I have thought that I would not detain you long with a written lecture, but suggest that after the conclusion of my remarks, which shall be as brief as possible, we should adjourn to the Reading-Room downstairs, most

kindly placed at my disposal by the Council. Here have been arranged with the cordial assistance of our Secretary, Dr. Tudsbery, examples of the apparatus used in metallurgical research. Some of the characteristics and properties of the alloys to which I am about to refer will be illustrated by actual experiments; tests of various kinds will be carried out and the apparatus will be shown at work. This will give you an opportunity of asking any questions you may desire to put, and also of seeing for yourselves the nature of some of the many problems metallurgists have to face. By making these actual demonstrations it seems to me that individual knowledge can be imparted to a greater extent than by a lecture of many hours.

Whilst the collection of apparatus could have been much enlarged by the many kind offers to contribute from various friends, I have wished to confine myself chiefly to those which my firm, at their Hecla Works, Sheffield, have collected and used; in other words they are representative only of the research-department of one particular organization.

Necessarily I can only show the instruments with which I have worked. This must not be taken to indicate that different appliances used by others may not be equally suitable. Moreover, those exhibited represent but a small portion of those required. The tests which will be made and the apparatus which will be shown may not be altogether new, but it may be hoped that to many of the younger members who have not had opportunities of seeing what I am about to describe, this plan of dealing with the subject may be of service. If this lecture proves of any assistance to them, it will be ample reward for the trouble taken in its preparation.

Finally, I trust it will be seen that metallurgy is no mean branch of science, and that its workers in every way deserve to occupy a position not inferior to that accorded to those engaged in other departments of engineering enterprise.

The Importance of this Science.—To give some idea of the gigantic nature of the operations of the metallurgist, and to show the enormous demand for iron, it may be mentioned that the estimated value of the world's products of iron and steel is now not far short of £1,000,000,000 annually. The output of pig-iron for 1905 was 53,300,000 tons, which is just double the production of fifteen years ago, and of this probably 80 per cent. is turned into steel. The total iron-ore extracted yearly throughout the world is almost 100,000,000 tons. The pig-iron production in the United States last year was 23,000,000 tons, or 4,000,000 tons beyond any previous record, the State of Pennsylvania alone producing nearly 750,000 tons more than the whole of Great Britain.

Notwithstanding the enormous strides made by other countries, the United Kingdom still holds the field in having produced the largest cumulative quantity of iron. We also yet export far more iron and steel than any other nation; twice as much as the United States, and nearly 50 per cent. more than Germany. This is not a little remarkable in face of the statements made by some who are continually predicting our decline. A paragraph appeared recently in an American technical journal ("The Iron Trade Review") bearing upon this aspect of the subject. It appears so much to the point that I think it will be appropriate to quote it here, especially as it is satisfactory to find commendation abroad, remembering how often we are severely criticized at home.

"With the United States, large exports of iron and steel products are generally a sign of adversity; with the United Kingdom they are a sign of prosperity. England's home market is her most important market it is true, but her iron and steel export trade is the most important of any country. Her exports are so widely distributed over the whole face of the globe, being by no means confined to her colonies, that their size is a good index to world conditions. Our (*i.e.*, American) exports vary widely from year to year, partly in relation to the varying degrees of prosperity at home. England's export trade is much steadier. It is not a dumping process, but involves the careful cultivation of trade, a policy which American producers have but lately adopted. The fact that England's production goes so much to foreign countries, as a result of trade building efforts, is in a measure responsible for her steady production, the figures showing none of the wild changes so notable in American production statistics."

The transmutation of the base metals into gold by the philosopher's stone would have produced but small results compared with the extraordinary advantages gained by the actual transformation of iron ore into the vast quantity of metallic iron, to which reference has been made; nor would it have compared with the real transmutations which are produced in iron by the addition of other elements and by heat treatment. No other metal can rank with iron in its importance. Millions of human beings throughout the world are extracting it in its oxidized form from the earth, and smelting and working it up into finished products.

Until recent times the manufacture of iron was carried on empirically, but since its production has been guided by the light of modern scientific knowledge the world's civilization has progressed by leaps and bounds. Under tho conditions of modern life the consumption of iron per head of population is an excellent index of the material prosperity of a nation.

In America this has now reached the high figure of 619 lbs. per head as compared with 387 lbs. in 1900, or 84 lbs. in 1856, just half a century ago. The world's total production of pig-iron in 1905 was

53½ million tons, representing an average consumption of about 68 lbs. per head.

Exhaustion of Iron Ore Sources.—It is unlikely that there will be any halt in the enormous demand for iron; therefore, as I have elsewhere shown, it is quite probable that by the end of the century, if the present ratio of increase continues, there will be a call for over 500 million tons of iron-ore annually; for we must remember that, in addition to existing areas of consumption, Eastern nations will, without doubt, before long enormously add to their demands. This naturally raises the question, Will our sources of supply run short? It is a problem which time alone can determine. It can, however, almost with certainty be foreseen that the known iron-ore fields of North America, Germany and England will be exhausted within one or two centuries from now.

An interesting train of speculation is aroused if we consider how the whole course of the metallurgy of iron might be considerably modified if electric smelting could be successfully carried out. At present iron can only be smelted commercially when the coal required is at hand; but electrical smelting might be effected by energy obtained from natural sources other than carbonaceous fuel, and then many more deposits of iron-ore would become available. This will be referred to elsewhere in the address.

Iron.

Let us now deal with the special qualities and properties of the metal with which we are interested this evening.

As regards its use, this appears to go far back into antiquity. Its application is believed by many to have been later than that of the more easily melted metals, though one of my predecessors in the Presidential Chair of the Iron and Steel Institute, Dr. John Percy, a metallurgist of great eminence, considered that the age of iron preceded that of bronze. However interesting these speculations may be, there is not time to deal with this aspect of our subject. It is sufficient to say that the use of iron was of great importance to the human race in the early history of the world, even if it was only used in comparatively small quantities as compared with the immense figures of to-day.

Swank, in his "Manufacture of Iron in all Ages," and Beck, in his mammoth work of 5,900 pages, "Geschichte des Eisens," show how ancient is the use of iron, and the able Secretary of the Iron and Steel Institute, Mr. Bennett H. Brough, has quite recently

contributed a most excellent Paper[1] on the early uses of iron which will well repay perusal by those interested in the subject.

The working of iron in its simplest form is beautifully described in "Ecclesiasticus":—"The smith also sitting by the anvil and considering the ironwork, the vapour of the fire wasteth his flesh, and he fighteth with the heat of the furnace; the noise of the hammer and the anvil is ever in his ears, and his eyes look still upon the pattern of the thing that he maketh; he setteth his mind to finish his work and watcheth to polish it perfectly."

That the commonplace metal iron can be worked into artistic forms in a manner not often credited is well illustrated by the beautiful inlaid iron- and steel-work done in Russia, of which, during the last few years, I have made a small collection. As I write, this is before me, and the high lustre which the metal takes, brighter and in some respects more interesting than silver, makes one wonder why more of this artistic work is not produced. This collection will be shown in the Reading-Room.

Composition.—In its position amongst the elements iron has the peculiarity of being surrounded by those in some respects analogous to it—nickel, cobalt, manganese and copper—which resemble one another in certain of their physical properties, such as specific gravity, atomic weight, and fusion-point; yet, notwithstanding these similarities, the world might dispense with the latter elements, but certainly not with iron. Whether these four elements have a common origin is a mystery that science even to-day has not been able to penetrate. There are grounds, however, for believing that they are in some way related to each other or have originated from one common stock.

Physical Properties.—Apart from those properties studied more intimately by the chemist, some of the chief characteristics of iron with which we are most concerned are: malleability, tenacity, ductility, elasticity, hardness, permeability, electrical and heat conductivities, resistivity, and fusion-point. Who would think that many of these properties can be so profoundly modified by being alloyed with other elements that it is almost impossible to recognize the product as being made up chiefly of the original element?

The following are some only of the most important changes which occur even when the iron largely predominates. About 0·20 per cent. sulphur, or even less, completely destroys the malleability when hot. In the alloy known as cast iron the fusion-point is

[1] "The Early Use of Iron." Journal of the Iron and Steel Institute, vol. lxix (1906, No. 1), p. 233.

lowered several hundred degrees by the presence of carbon and other elements. Pure iron has a Brinell hardness-number of 85; this is increased in hardened carbon-steel to about 800—that is, ten times. The resistivity of pure iron is 10 microhms per cubic centimetre, which in the iron-nickel-manganese alloy referred to elsewhere is increased to 95 microhms. Again, pure iron has a maximum permeability of 4,000 C.G.S. units, whereas in the manganese-iron alloy this is reduced to 1·3 C.G.S. unit.

In its qualities under mechanical tests the changes are equally profound. Its elastic limit in the pure state is about 10 tons per square inch; this can be increased to over 100 tons per square inch in nickel-chromium steel. Similarly the tenacity, originally 19 tons per square inch, or even as low as 5 tons per square inch in cast iron, can be increased to 110 tons per square inch, or if wire-drawn material is considered, to over 200 tons per square inch. I have produced a nickel-carbon steel (carbon 0·41 per cent., nickel 20 per cent.), not wire-drawn, which when tested in liquid-air had a tenacity of 154 tons per square inch, with 15½ per cent. elongation. The ductility or property of elongation of iron may be practically nil, or increased to over 70 per cent. in the case of certain iron-nickel-manganese alloys.

With such an extraordinary range of qualities it can, indeed, be said there is no other metal known which is so curious and at the same time so valuable to mankind.

Crystallization.—To what can these remarkable variations in quality or character be ascribed? Such a question cannot be answered briefly, but it may be said that they are chiefly due to various forms of crystallization, which are themselves, no doubt, largely produced by the particular elements entering into combination with, or modifying the properties of the matrix iron, and further by the particular kind of heat-treatment and cooling to which the metal has been subjected. The type of structural conditions so produced largely determines the physical properties of the metal. It is for this reason that the great work originated by Dr. H. C. Sorby in 1857, in connection with the microstructure of iron and its alloys, has so profoundly influenced the metallurgy of iron. The term "crystallization," though a simple one, well describes phenomena of the highest order of importance. It is one all can understand, and is well employed in describing the structure of iron. Microscopy, termed as regards metals "Metallography," is really a study of the crystallization of iron and other metals. It has now become an essential branch of metallurgy, though its use must always be correlative with other physical observations.

The great importance of this subject of crystallization is clearly set forth in a remarkable Paper,[1] "A Study in Crystallization," contributed by Professor J. H. Bowman to the Society of Chemical Industry in October last. As the general phenomena described by Professor Bowman appear to have very considerable bearing upon the crystallization of iron and its alloys, this Paper is well worthy of study by the metallurgist. Whilst there are also many intermediate stages in crystallization, as described in this excellent Paper, the following four principles are stated to be operative: "Initiation," probably the most important of all; "repression," relating to currents set up and their rate of action; "relay," the process by which compound crystals are formed; and "curving," when the crystallizing force is nearly equalled by the resistance of the medium, the crystal seeking the line of least resistance.

As a rule, in iron and steel the larger the granular structure the weaker and more brittle is the product. This at any rate is true of steel. Probably the lower the percentage of carbon, that is, the softer the steel, the less important is this point, but in higher carbon steel large or coarse granular structure is fatal to the quality of the material.

Iron is more sensitive, and also has the power of varying its crystallization or form of structure in a greater degree, than any other metal. These forms of crystallization seem to divide themselves into two main types, viz., coarse and fine granular, with many intermediate grades.

The whole art of producing steel of high quality consists in obtaining and controlling the type of crystallization desired. One of the most important factors is that of temperature, but until comparatively recently there were no means of checking this; we had to depend on the eye alone. This human instrument was too uncertain, except when working with special brands of steel, such as tool-steels, these usually being bars of small dimensions and dealt with in the smith's shop. It was not, therefore, to be wondered at that so many irregularities arose during the early production of what may be termed modern or special steels. These steels would be practically useless without our present knowledge of their heat-treatment, which means controlling the crystallization. It is singular how demand must arise and the environment be favourable before advance can be made. We are now on much safer ground, thanks chiefly to our means of accurately determining high temperatures, and the engineer can depend upon receiving special steel, which, when carefully and properly made, is a material thoroughly trustworthy.

[1] Journal of the Society of Chemical Industry, vol. xxv (1906), p. 143.

Problems in Metallurgy.

Having dealt briefly with iron and its properties, I will proceed to consider the important question of how it is possible to throw light upon the extraordinary changes which take place, and so profoundly influence the metal, whether by heat-treatment or the addition of various elements. Although only a hurried glance can be given to the subject in a lecture occupying one evening, in the Reading-Room attempts will be made to show how some of the desired results are reached, and how in the future solutions of many of the problems may be found.

The problems of metallurgy are many-sided, and the aid of almost every branch of science has to be invoked. In spite of all the progress made, great as it has been during the last decade, no finality is in sight, no place where the metallurgist may rest and say, "My work is complete." Looking forward to what remains to be done, metallurgy, like other sciences, seems to stand only on the threshold of the Temple of Knowledge; looking backwards it appears illumined with a flood of light compared with the Cimmerian darkness of the alchemists' period. The practical metallurgist needs the heart of a true worker and the spirit of an explorer as he steers through the maze of "unsolved problems" that beset his course. Happily, he has to guide him on his way many beacons that have been erected by friendly workers in other sciences—the chemist, the microscopist, the electrician, the physicist, and the mechanical engineer. If the generous aid given by these co-labourers does not enable all problems to be solved, at any rate it has thrown light into many dark corners, and we have always the certain knowledge that there is an answer to every riddle Nature sets, and harmony in all her laws if we have the wit and patience to classify them.

Special Steels.—The profound modifications produced in iron and its properties by carbon, nickel, chromium, manganese, tungsten, and other elements, have been fully dealt with in the literature of metallurgy during the last twenty years. The Paper which I had the honour to read before this Institution in the year 1887 was, so far as I know, the first systematic presentation of the influence of alloying iron with an element other than carbon. The investigations then set forth have developed into a long series of further researches, which have been described in my Papers read before this and other Institutions.

The development of what are now known as alloy or special steels

has been very great. Modern progress is more or less bound up with advances in metallurgy.

Wrought iron and ordinary carbon-steel, although of great value, often do not meet the necessities of modern constructional engineering, so that special steels must be used. Increased speeds, and other conditions involving greater wear and tear, are the characteristics of the present age. Let us take one specific case—that of the motor-car. Its construction from iron alone would be practically impossible; the great success of the French makers of motor-cars has been largely due to the attention they have paid to the production and employment of steels specially suitable for this work. Happily the fact is becoming recognized in this country. The importance of this industry is shown by the fact that it is estimated that France alone has an annual production of 25,000 motor-car chassis.

Metallurgists who study the manufacture, treatment and application of these special steels during the next quarter of a century will be among those who confer the greatest benefits upon mankind.

Heat Treatment.—As an illustration of the complex nature of the problems with which the metallurgist has to deal, I will specially refer to one—the effect of heat-treatment upon the metal iron and its alloys.

It is well known that chemical activity is greatly increased by a rise of temperature, and this may partly explain the extraordinary changes brought about in iron and steel when heat-treated. Direct evidence on this point is difficult to produce; we must be content to know that by certain heat-treatment profound changes do occur in the physical qualities of the iron or steel. This applies more to the material known by the generic name of "steel" than it does to iron. Iron seems less sensitive to heat-treatment; that is to say, it is less affected by varying conditions of temperature. Therefore the remarkable changes we are to study refer chiefly to iron alloyed with other elements. Carbon-steel forms a class in itself, but in all the special steels or alloys of iron, carbon must be present in greater or less quantities; in fact, most of them would be useless in the absence of this metalloid.

Let me give one illustration of the remarkable effect of heat-treatment upon an ordinary carbon-steel, of tool-steel quality, having the following composition—carbon, 1·16 per cent.; silicon, 0·07 per cent.; manganese, 0·37 per cent. Although it is generally known that such a steel will harden at certain temperatures, and will not harden at others, it was only quite recently discovered how fine is the dividing-line—not more than a few degrees. Mr. S. N. Brayshaw, M.I. Mech. E., even claims that but 1° C. will cause consider-

able difference in physical qualities, and I believe he is not far fron the truth. A joint research by him and myself is at present being carried on, which, it is hoped, may throw light upon this interesting question.

There is nothing mysterious in the knowledge gained in this field of research; but it has taken centuries to discover these important facts. Now, by means of modern pyrometers, all ranges of temperatures can be read with great accuracy, and it is found that carbon steel of the composition mentioned, when heated to 725° C. and quenched in brine, will afterwards bend cold 43°, its Brinell hardness-number being 228. Quenched at 735° C., or 10° higher, the quenched specimen, when cold, bends only 1·5°, the Brinell hardness-number being increased to 512. Quenched at 740° C. the bend is nil, and the hardness-number 713; in other words, the steel is completely hardened. Thus we have the remarkable fact that by increasing the temperature only 15° C. we get the phenomenon of complete hardening. The small difference of 15° C. (27° F.), within which range hardening or non-hardening results occur, represents no more than the change in temperature between a spring and a summer day, yet such slight differences in temperature entirely revolutionize the structure of steel. An experimental demonstration of these facts will be made after the lecture.

It will thus be seen how delicate is the nature of the metallurgist's work, and it must be remembered that I have here only dealt with one type of temperature change—that relating to hardening. Other important changes are those occurring both at lower and higher temperatures. Further, there are critical changes at the high temperatures of 900° to 1,000° C., and these, it must be remembered, are temperatures at which forging and rolling are usually carried on. There are also variations in hardening-temperatures. The one produced at about 720° to 740°, to which I have referred, is merely the first landmark, the position of which varies according to the nature of the steel, whether low or high in carbon, and whether it is a special or alloy steel. This term is used in contradistinction to carbon-steel, though the latter, too, is in reality an alloy steel. There are changes in temperatures used for toughening purposes, most of them well below the hardening-points, and in certain cases critical changes occur, not only down to atmospheric temperature, but even at the temperature of liquid-air, or −182° C. Colonel Crompton has found a "change" of very interesting character which I hope he will describe to this Institution before long. Again, in dealing with changes of temperature, the influence of mass must be considered. At a given crystallization produced by temperature a

large mass will not necessarily behave in the same manner as a small one, and the duration of the heat-treatment is also important.

We thus see not only how sensitive is iron in the form known as steel, but also how exceedingly important are the correct methods of determining the exact temperatures at which these changes occur and at which the material is treated. It is for this reason that I put in the front rank of the metallurgist's tools those by which he solves the problems which hinge upon accurate means of determining temperatures, whether they be high or low.

As striking instances of the importance of heat-treatment, I may mention the hardness of the face of armour-plate, made to keep out projectiles, and that of the projectile, made to perforate the armour. The entire success or failure of their manufacture turns upon heat-treatment.

In the Reading-Room will be shown a number of instruments used for the measurement of temperature, and experiments will be made to bring out the points to which I have referred.

Tests will also be undertaken to show the profound magnetic changes produced in iron by temperatures ranging from that of liquid-air to temperatures of 1,000° C. or more.

With the latter is closely associated a most interesting and suggestive phenomenon—recalescence—for the discovery of which we are indebted to an Englishman, Professor W. F. Barrett, F.R.S.

Experiments will also be made to demonstrate the curious magnetic properties of high nickel-iron alloys, and iron-manganese alloys. These experiments show that, whilst the alloys appear practically non-magnetic at atmospheric temperatures, upon cooling down in liquid-air they become considerably magnetic, and remain in this state until again raised to about 500° C., when they become non-magnetic. This cycle can be carried out as often as desired with the same result.

These structural changes must be very great, for the special steel containing 20 per cent. of nickel, which is almost non-magnetic or only feebly so, has a tenacity of 44 tons per square inch, an elongation of 55 per cent., a reduction of area of 63 per cent., and can be readily machined at ordinary temperatures. Upon being immersed in liquid-air, however, it becomes strongly magnetic, its tenacity increases to the extraordinary figure of 157 tons per square inch, whilst its ductility still remains fairly high, namely, 15½ per cent., and it can now be machined only with difficulty. This steel after returning to atmospheric temperature retains a tenacity of no less than 115 tons per square inch, or more than 2½ times that of its original condition, and has an elongation of 4½ per cent.

The alloy of iron and manganese with which I have worked for

so many years is not, singular to say, affected by any change in temperature, whether the highest or that of liquid-air; it always remains non-magnetic except when annealed for a long period.

Fatigue.—An interesting problem, often discussed, is whether iron or steel becomes changed in its properties by what is termed "fatigue." Most probably it does not if the material is, in the first or original state, properly prepared. Failures, so-called, of this kind are generally due either to the steel possessing internal flaws, which are often only detected by an examination of its micro-structure, or to its not having been in the proper condition when sent out to the user. So-called "mysterious failures" are generally due to improper heat-treatment, and are quite apparent when adequately investigated.

A recent writer states that after long experience he has found that steel does not change by fatigue, that is, under ordinary working loads; "once right, always right" is his explanation. This investigator took a large number of specimens that had been many years in use, some having given satisfactory, some unsatisfactory results, and he detected no difference or break-down in the mechanical qualities. Probably this conclusion is correct.

At Watertown Arsenal, the official testing-department of the American Government, interesting tests have been made upon iron which had been submitted to severe mechanical treatment 23 years ago, having been stressed close up to the elastic limit and then laid on one side. No change in quality could be detected. The characteristics of the earlier over-strained condition produced by the loads applied so long before, still remained.

Electro-Thermic Smelting of Iron and Steel.—There are many unsolved problems to be worked out in connection with the production of steel. The Bessemer and Siemens-Martin processes have been carried to a great refinement, and the material produced by them, as regards quality, holds a high place in engineering construction, whilst the rapidity of production and low cost they have made possible are economic advantages of a high order. Beyond improvements in detail, none the less important because they are small, these processes remain in principle much as they were originally. It will probably be a long time before they are supplanted.

There are those who look forward to an electrical method of producing iron and steel. If any practical system of this nature for converting iron-ore into pig-iron or steel could be introduced, using the stored-up powers of Nature instead of burning carbonaceous fuel, the revolution in practice would be great. Probably more than one hundred million tons of coal, equal to about one-seventh of the world's total output, are used annually in the smelting of iron, to say

nothing of the further large quantities employed in the subsequent working of iron and steel into more finished form. Where water-power and suitable iron-ore can be found together, no doubt, satisfactory electrical smelting practice will be developed, but this can only come slowly.

Pioneer work is being done in Sweden, France and Canada, in electrical smelting for the production of steel, but unless water-power can be obtained at economical rates it would seem that the application of this system must remain very limited; that other sources of power should be used at present appears to be out of the question from an economical point of view. Moreover, the electric furnace does not purify steel more than other furnaces not specially adapted to that purpose. Bad steel can be produced by it as easily as by the ordinary processes. Some of us know how often the old type of crucible-steel melting, so largely practised in Sheffield, has been threatened with extermination, but more material is now produced in this way than ever before. The electrical system has in this older method, notwithstanding its extraordinary wastefulness, a competitor that will not soon be annihilated. There is no magic in the electrical method as it would almost seem some would have us believe. Steel made by it shows similar analysis, and has the same physical qualities as that produced in other ways.

Electric Furnaces.—An important question in connection with electric furnaces is, whether they can ensure uniformity of temperature. It is well known that they are apt to produce steel which is much colder at the top of the molten bath than underneath; this is, of course, objectionable. Of the many failures with electric furnaces we hear little; it would be interesting to know more about them. I say this in no disparagement of a "young" process, but to prevent the uninitiated being dazzled by the mere term "electric."

It is stated that the efficiency of the electric furnace is already comparatively high, say 50 per cent., but under present conditions it would still be more expensive to develop heat, at any temperature within the range of a coal-fired furnace, by electricity than by coal; that is, if electricity has to be generated by steam-power, even with plant of the highest efficiency.

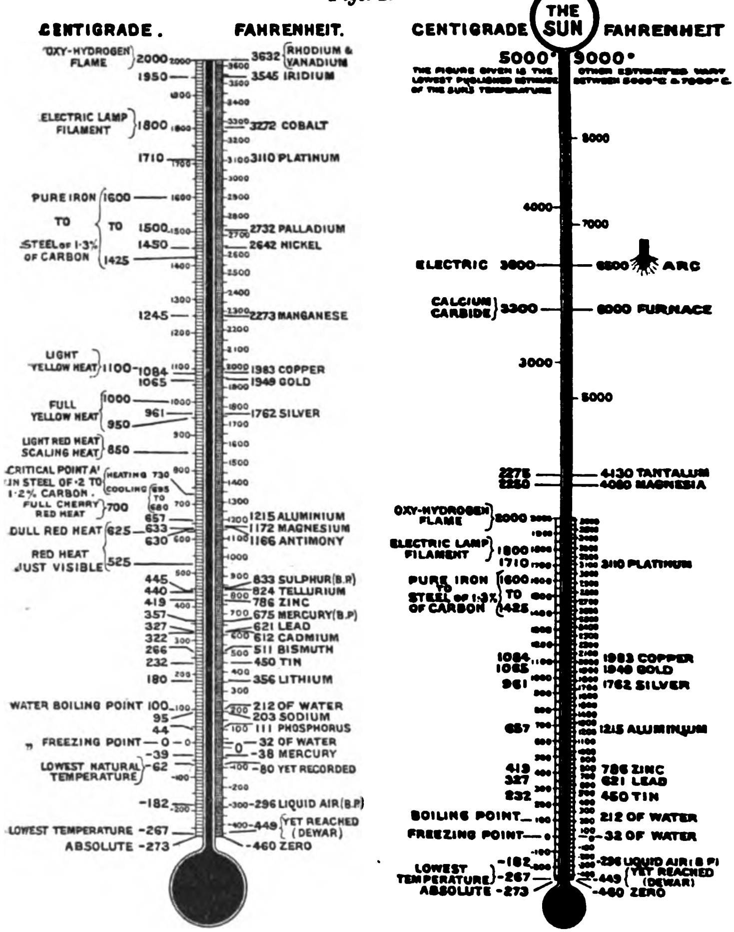
The electric furnace has a range of temperature of about twice that of the ordinary steel furnace, so that it will extend up to about 3,000° C. Reactions which take place within certain limits of temperature as now practised may be reversed at the higher range made available by the electric furnace.

Whilst speaking of high temperatures it may be pointed out that no one knows the behaviour of the elements present in the sun, the temperature of which is estimated to be between 5,000° C. and

6,000° C., neither can we foresee what will be the behaviour of metal at temperatures above the limit of our present ordinary furnace that is, above about 1,500° C.

The large temperature diagram shown in the Reading-Room (*Figs. 1*), which takes the form of an exaggerated thermometer-scale

Figs. 1.



TEMPERATURE-CHARTS, SHOWING THE PRINCIPAL MELTING- AND FREEZING-POINTS AND ALSO OTHER IMPORTANT METALLURGICAL TEMPERATURES.

will give a comparative idea of the extraordinary temperature which must exist in our great luminary. In view of the limited knowledge gained from even our highest terrestrial temperatures, it will be seen how difficult it is for us to understand what is there occurring.

PART II.

Having indicated some of the problems met with by the metallurgist, the means by which we may hope to arrive at a solution of many of them may be now described.

As I have already intimated, it is not possible in an address of this nature to do more than touch upon some of the most interesting features of metallurgy. The following pages can, therefore, only be devoted to a general survey of the ground to be explored.

The order in which the demonstrations and experiments presently to be shown to you are dealt with is as follows:—

I. Literature.
II. Alloys, and their special properties.
III. Chemistry and chemical laboratory apparatus.
IV. Metallography.
V. Heat-treatment; including the application of pyrometry and the study of recalescence phenomena and other changes.
VI. Electricity in relation to metallurgy.
VII. Testing of various kinds.
VIII. Tests at liquid-air temperatures.
IX. Expansion coefficients.

I.—Literature.

The literature and reminiscences of the past shown in the Reading-Room represent a collection of the chief metallurgical works, commencing with those by Albertus Magnus and Agricola of the fourteenth and fifteenth centuries, down to the best modern works. There is also exhibited a collection of portraits of about fifty prominent workers in scientific metallurgy, dating from early to recent times.

I am at present compiling a list as complete as possible of various metallurgical literature. Aristotle as far back as 384 B.C. described the manufacture of Indian steel. The wonderful work of Agricola (1490–1555), the Bessemer of his day, "De re Metallica," may be specially emphasized.

II.—Alloys and their Special Properties.

As this subject has been dealt with in the first part of the address, and the peculiar properties of certain alloys have been there indicated, a brief reference only to those exhibited will now be made.

In the brittle iron-manganese alloy containing 4½ per cent. manganese, the properties of iron seem quite reversed. Although the carbon present is comparatively low, this alloy is more brittle than cast iron. With an increase of manganese to about 12 per cent. the properties of this alloy again entirely change, and it becomes of more than ordinary interest. When forged and treated, this steel has a tenacity of about 60 tons per square inch, with a ductility of 40 per cent. to 50 per cent., or considerably more than that of pure iron. Yet the determining factor, manganese, is in itself an exceedingly brittle metal. It also becomes practically non-magnetic, and, unlike certain nickel-iron alloys which also appear to be non-magnetic, but are reversible, it cannot be rendered magnetic even by quenching in liquid air, nor does ordinary heating render it magnetic. When it is considered that the same metal, manganese, combined with copper and aluminium in the material known as the "Heusler" alloy, gives a magnetic product, although no iron is present, it will be recognized what a wonderfully wide field for research is offered by alloys of various kinds. The results to be expected are so curious that it is not possible to generalize from one to another; each alloy must be worked out.

Whilst speaking of magnetic properties, one of our profound thinkers in electrical problems, Dr. J. A. Fleming, F.R.S., in a joint Paper by him and myself to the Royal Society in June last, considers it is very probable that ferro-magnetism, *per se*, is not a property of the chemical atom, but of a certain kind of molecular grouping. The importance of this cannot easily be overstated. It shows that, in spite of the fact that ferro-magnetism has been hitherto regarded as the peculiar characteristic of certain metallic elements—iron, nickel and cobalt—this may depend eventually upon molecular grouping, composed of a comparatively large number of molecules; hence it may be possible to construct alloys which are as magnetic as, or even more magnetic than, iron itself.

Attention may be drawn to the brilliant researches on alloys of iron with other elements by Mr. L. Guillet, of Paris, who has this year been awarded the Carnegie Gold Medal.

Another illustration of the peculiar nature of these iron alloys is

that of "Resista" steel, already described before the Institution. This material contains 79 per cent. iron, 6 per cent. manganese, and 15 per cent. nickel. In the cast form it can be bent double when cold, as illustrated by the 2½-inch bar shown. When forged, its tenacity is 58 tons per square inch, with the extraordinary elongation of 60 per cent. to 70 per cent. This alloy is only feebly magnetic until cooled in liquid-air, when its magnetic properties are considerably increased, but it is not embrittled by this treatment. A singular fact regarding this alloy is that if either the manganese or the nickel is omitted, an extremely brittle product is the result; but combined together they produce the most ductile iron alloy known.

The curious electrical properties of this and many other iron alloys have been carefully studied by Professor W. F. Barrett, F.R.S. They were illustrated by a number of experiments and researches in which he and I collaborated.

A number of alloys, also metals, having peculiar properties will be shown, including "Inert," pyrophoric alloy, magnetic copper alloy containing no iron, tantalum, manganese, chromium, 75 per cent. silicon alloy, hematite cast iron containing only 0·33 per cent. silicon, yet at the same time no less than 2·03 per cent. graphite.

The pyrophoric alloy is an alloy of iron containing 30 per cent. cerium and also other rare metals. The pyrotechnic display on scratching with a file makes it of spectacular interest.

"Inert" is a non-magnetic cast iron containing about 13 per cent. manganese, yet at the same time it is machinable.

From this short summary it will be seen how extraordinary are the properties of different alloys, and that a knowledge of each of the metals of which they are composed may not necessarily be any guide to the properties of the alloy. The field is immense, and the future progress of the metallurgical world largely depends upon research which will enable us to understand and interpret correctly the laws at work in producing these curious results.

In a useful Paper on "Ferro Alloys" recently read before the Institution of Mining and Metallurgy, Dr. O. J. Steinhart points out the importance of this subject. With the many metals and alloys now at our disposal the number of useful alloy-steels which may be produced has been greatly extended. The study of these affords a field of such magnitude that it requires the ceaseless investigation of master minds to select those combinations which give the desired results with the least expenditure.

III.—Chemistry and Chemical Laboratory Apparatus.

The chemist is the chief assistant to the metallurgist. As we have seen, the composition of an alloy, no matter how carefully considered by the metallurgist beforehand, may work out in an entirely different manner from that expected. All alloys have to go through the furnace, and the changes there produced must be submitted to the chemist in his laboratory. It is he who informs the metallurgist of the ultimate composition of the alloys which he has produced.

The element of predominating importance in the metallurgy of iron is carbon, and amongst apparatus to be shown are those used for correctly determining the amount of this element present.

In addition to apparatus showing carbon combustion and ordinary carbon calorimetric methods, there will also be exhibited methods of stirring solutions by means of air-blasts; the Sartorius balance, which is capable of such delicate weighings that it will detect a difference of $\frac{1}{10}$ of a milligramme, or 0·000003527 (*i.e.* $\frac{1}{283000}$) of an ounce; apparatus for determining sulphur in iron and steel, enabling the result to be obtained in 20 to 30 minutes, according to the solubility of the specimen.

IV.—Metallography.

The microstructure of iron and its alloys is an important branch of research to the metallurgist, but it must be taken correlatively. Its use is of great value in enabling the investigator to form an idea of the structure of the metal with which he is working. Dr. H. C. Sorby, F.R.S., who delighted everyone at the recent Sheffield meeting of the Iron and Steel Institute by his presence when he joined in the discussion on Professor Arnold's Paper, little imagined when first describing his methods in 1857 what an important adjunct they would prove to metallurgy. This is another instance of the great value to the metallurgist of the work done by the pure scientist.

This important branch has been followed up by Martens, Arnold, Stead, Howe, Sauveur, Ewing, Rosenhain and others.

The numerous micro-constituents of iron and its alloys must necessarily be somewhat puzzling to the uninitiated, and unfortunately their study has been rendered more complex than it need have been. These numerous constituents, some of them almost christened before being born, have bewildered many, but it must not be forgotten that the patient researches being carried out by scientific men in this country and abroad are bearing good fruit, and a less complex

nomenclature is being gradually evolved. It must be distinctly understood that in the study of alloys no one branch of investigation can solve the problems met with in metallurgy. It is by a correlation of the whole of the facts that true and lasting evidence will alone be obtained.

In addition to ordinary microscopes for the examination of metallic sections, there will be shown this evening photomicrographic apparatus suitable for general metallurgical work, capable of making photographs of sections at magnifications of 25 to 2,000 diameters.

There will also be exhibited typical sections polished and etched for examination, as well as the apparatus for polishing such sections.

V.—Heat-Treatment; Including the Application of Pyrometry with the Study of Recalescence Phenomena and Other Changes.

(*a*) *Pyrometry.*—Such immense strides have been made in this branch of science during the last decade that when we look back the advance appears marvellous, considering the short time that has been occupied by the work.

It was but a few years ago that any correct determination of high temperatures became possible; chaos is the only word suitable to the conditions previously existing. Misleading data only increased the confusion. Now, by means of the modern pyrometer, temperatures up to 1,100° or 1,200° C. can be determined within a few degrees; in fact, Callendar claims that by his research-instrument it is possible to indicate within one-tenth of one degree Centigrade. Modern advance in metallurgy largely depends upon working within extremely narrow ranges of temperature in heat-treatment, and for this reason our debt is great to the scientific men in this and other countries who have helped to solve this important problem. Four names are specially prominent—Siemens, who originated the electric resistance pyrometer; H. le Chatelier, a Frenchman to whom we are all indebted; and Callendar and Roberts-Austen of this country.

There will be shown a number of pyrometers, both indicating and recording, including electrical and optical types; apparatus for calibrating; and apparatus for obtaining heating- and cooling-curves to show the recalescence and critical points of iron alloys.

To give some relative idea of terrestrial temperatures, and to show how they compare with those believed to exist in the solar regions, a scale will be shown which has been prepared upon thermometric lines, *Figs. 1*. This affords a simple way of indicating the extraordinary

temperatures prevailing in our great luminary, and brings home to us how gigantic must be the forces at work there. It enables us to understand how at such enormous temperatures bodies we here know as elements may well be resolved by this intense heat into perhaps a few primary elements. Biblical language well describes such an extreme temperature by the expression "and the elements shall melt with fervent heat."

(b) *Recalescence.*—This phenomenon and other changes produced in iron by heat-treatment were discovered by Barrett, a representative of pure science. Osmond of France, the Bessemer gold medallist of this year, saw the wealth of information which lay in this advance, and the beautiful methods of obtaining heating- and cooling-curves he initiated have been invaluable in enabling the metallurgist to know how to heat-treat in a scientific manner the particular type of steel with which he is working. Osmond's work has enabled profound modifications of great practical value to be obtained with regularity and certainty.

Recalescence-curves will be shown, and the various change-points will be seen in formation. These changes in heating and cooling, many of them occurring suddenly, and the phenomenon of recalescence, will be traced by means of special apparatus.

(c) *Heat-Treatment.*—This branch is really comprised in the work of the two preceding subjects, but a brief explanation of its practical value may be given.

By means of the pyrometer, which enables a careful study to be made of the influence of varying heat-treatments, the metallurgist is able to bring about important changes of a physical nature in a manner unknown up to the last few years.

Whilst the human eye has in the past proved a useful pyrometer, it was comparatively feeble, and was altogether unsuitable for dealing with the requirements of modern metallurgical conditions If surrounding conditions were never to change, or the human temperament did not vary from time to time, or the operations were always carried on in darkened rooms, then for certain kinds of work the human pyrometer would carry us a fair distance. But changes occur in iron and its alloys which exhibit no colour guide. As already pointed out, a few degrees of temperature may be of vital importance. The qualities or types of steel are nowadays so multitudinous that in the treatment of them the cleverest human agent is useless; in fact, his observations are often misleading. The accurate determination, therefore, of exact temperatures is now of vital importance and is becoming more so every year. Steel which is worse than useless, nay dangerous, can be transformed into

the safest of products. All this increased knowledge adds to the safety and security of the world's inhabitants. To illustrate and describe a tithe of the applications of heat-treatment would require not a lecture but a book.

VI.—Electricity in Relation to Metallurgy.

(*a*) *Electric Furnace.*—I have elsewhere dealt with the probable future of electrical energy as supplied to the more important branches of metallurgy, such as the smelting of iron-ore, the production of steel, and other operations.

A number of small laboratory furnaces worked by electrical energy will be shown, including those used for heat-treatment and melting-purposes.

(*b*) *Electrical and Magnetic Qualities and Measurements.*—It is not unnatural that the most magnetic metal known, iron, should offer problems of profound interest to the scientific investigator; beyond this the study of the electrical and magnetic properties of iron and its alloys is of the greatest practical value; in fact, if the magnetic properties of iron were taken away, the world would lose a great part of its artificial illumination, for electrical energy, practically speaking, could not be generated.

The range in magnetic capacity varies in an extraordinary manner, from practically nil in the iron-manganese alloy, to pure iron, the most permeable and magnetic metal known.

Determination of magnetic capacity, permeability and resistance, are therefore of great importance, for the electrical engineer largely depends upon iron for the construction of his machinery. The many complex instruments and apparatus now used make it impossible to show more than a few of the simpler ones used in the testing of iron and steel.

VII.—Testing of Various Kinds.

We here enter upon a domain in which the civil engineer is largely interested. Whilst he may not directly concern himself so much with the manner in which the material brought to him by the metallurgist is produced, he now takes great interest in its properties. He enquires how it will stand in every-day service under shock, wear and tear, atmospheric influence, and other conditions to which it may be subjected. He properly says, "These wonderful tests are very well, but can you always produce them

regularly? Is the material economical in practical use?" He also asks other questions of a like nature. He must not be too exacting, however, for a friendly word of encouragement from the user to the metallurgist has the greatest influence in spurring him on to meet the increased severity demanded by modern conditions, even if he at first fails. Bessemer's first rails were laughed at, and yet to-day statistics tell us there are 525,000 miles of single track of railway in the world, or a total length of considerably over 1,000,000 miles of rails. This means that there is a total of about 71,676,000 tons of rails in use at the present time, most of them made by the Bessemer process.

May I here say a word to the civil engineer? Be patient with the metallurgist; give him a helping hand; when designing your machines, or drawing up your specifications, call him into your councils, and you will assist him to meet your requirements, thus benefiting yourself. It is for this reason that standardization of tests must prove of great value, and hasten progress in this country. Unfortunately, we are often too apt to be suspicious of what is new, in this respect being somewhat behind our American cousins.

The examination of mechanical properties, as they are usually termed, has in the past largely consisted in determining the tenacity and ductility by the static method. New types of tests are, however, springing up. They represent an attempt to test materials under conditions more nearly approaching those of actual service—for example, under vibratory, alternating, shock, bending, and shearing stresses.

Apparatus for tests of this kind necessarily occupy much space and cannot well be exhibited except in a testing-room, but the various machines used are now becoming well known. They include those of Arnold, Guillery, Avery, Frémont, Izod, and others.

Test-pieces broken by some of the above methods will be shown which open up quite new fields for research. They prove that it will not do to rest content with ordinary static tests, useful as these are, for they do not throw sufficient light on many important facts met with in practical everyday work.

To show the manner in which an ordinary static test may mislead, the following interesting experiment was carried out. Mild steel of best quality, containing 0·12 per cent. carbon, 0·02 per cent. silicon, 0·02 per cent. sulphur, 0·02 per cent. phosphorus, 0·28 per cent. manganese, was obtained; this in its properly prepared condition possessed the following mechanical properties: an elastic limit of 16 tons per square inch, a tenacity of 28 tons per square inch, an elongation of 35 per cent., and a reduction in area of 65 per cent.

Under the notch or nick test this bent double cold, as shown by the specimens exhibited.

Portions of the same steel were heated to about 1,200° C. and allowed to cool slowly. The results were as follows—elastic limit 9 tons per square inch, tenacity 22 tons per square inch, elongation 46 per cent., reduction in area 64 per cent.

It would naturally be assumed with a rise of 10 per cent. in elongation, that is, to the high figure of 46 per cent., and the excellent reduction in area of 64 per cent., that the material would be in a still better condition to resist shock than the original specimen, but under the dynamic shock or notch test, remarkable to say, it snapped like cast iron, not even bending 1°. Yet a test-piece of the same size and from the same material, but not nicked, bent double whilst cold under shock. This is a most curious result, and shows how careful users of steel should be in its heat-treatment, as without doubt brittleness can be developed under certain conditions at much lower temperatures than the one above mentioned. It is also clearly seen that the existence of the bad qualities, brittleness and low resistance to shock tests, are not shown by the ordinary tensile tests.

There is no doubt that careless and improper heat-treatment, either originally by the maker or afterwards by the user, is largely accountable for most of the so-called mysterious failures of boiler-plate and other steel for structural purposes, and yet the existence of the defects or the peculiar brittle structure are not detected by the usual tensile tests.

It may be mentioned that under these notch tests "Resista," the curious nickel-manganese-iron alloy described elsewhere, required not only twice the usual energy to produce bending, but also bent double unbroken.

A useful adjunct for ascertaining the hardness of constructive materials is that introduced by Brinell, whose simple but effective plan of indenting the material to be examined under a definite pressure by means of a hardened steel ball gives very valuable results. This indentation is duly measured with a reading-micrometer, and classified under its "hardness-number" on the "Brinell scale" according to the position. It varies in the case of Swedish charcoal-iron from a hardness-number of 90 to about 800 in that of hardened steel. It is surprising to find that so much useful information can be obtained from such a comparatively simple test. The hardness-number does not tell us all we want to know, but in conjunction with other physical or mechanical qualities it gives a useful idea of what will be certain special qualities of the metal tested.

Fatigue-tests are well brought out by the Arnold alternating-stress

machine. This gives excellent results in connection with mild and other kinds of steel.

An important branch of industrial progress depends upon the ironfounder, a technical man of whom little is heard. In this connection it may be interesting to call attention to the useful work being carried on in America by the Foundrymen's Association, which is doing its utmost to introduce suitable standardization tests there. A similar association has been founded in this country, and is doing good work. Amongst standard tests adopted in America is the Keep method of preparing test-bars in the foundry, including the simultaneous determination of shrinkage, chill, and strength. His apparatus and a set of test-bars produced will be shown.

VIII.—Tests at Liquid-Air Temperatures.

A new branch of investigation has recently been initiated—the examination of the properties of iron and its alloys at extremely low temperatures. This research has been made possible by the work of our Honorary Member, Sir James Dewar, to whom our thanks are due, not only for having made it possible to produce liquid air, but for the means suggested for carrying out these tests to which I refer. Although scarcely coming under mechanical tests of an ordinary nature, this research occupies a position so peculiarly its own that it seems worth while to make a brief reference to it. Those interested will find a full account in my Paper to the Iron and Steel Institute, read in May 1905. Many remarkable properties of iron alloys, which can be arrived at in no other manner, are brought out by these scientific investigations.

The extraordinary embrittling effects of liquid-air, representing a temperature of $-182°$ C., are fortunately not commonly experienced on our globe; but a serious accident recently occurred abroad owing to the breakage of a steel rail in service under conditions of low temperature. It would appear, therefore, that this new branch of research has an important practical bearing.

Further, by an examination of the properties of iron and its alloys at liquid-air temperatures, many curious physical facts have been brought to light. The purest and toughest wrought iron at this low temperature becomes as brittle as hardened steel, and is easily broken. The temporary nature of this brittleness is shown by allowing the specimen to return to ordinary temperatures, when its ductility is restored.

Although in most cases embrittling effects follow on immersion

in liquid-air, there are several notable exceptions, including an iron-carbon-nickel alloy which increases in tenacity to nearly three times its original strength whilst quite a considerable degree of ductility still remains; in an iron-nickel-manganese alloy, not only does the tenacity increase from 49 tons to 75 tons, but the ductility rises from 42 per cent. to 57 per cent.

The effect of liquid-air, too, upon the reversibility and irreversibility of various special steels is most curious. Nickel-steel containing 20 per cent. of nickel, which is non-magnetic, or feebly so, at ordinary temperatures, becomes considerably magnetic at 182° C., and this property is retained on reaching ordinary temperatures again. Thus the specimen indicates a transformation on cooling which is not modified on re-heating over the same range. The alloy is found to have expanded permanently during this treatment. The only alloy not affected in its non-magnetic properties is the special alloy of iron and manganese before referred to.

IX.—Expansion Coefficients.

A fascinating line of research is opened in the study of the peculiar behaviour of different iron alloys, and the examination of their contraction and expansion over a range of temperatures from − 200° C. to 800° C. Experiments will be shown to illustrate this.

By means of the ingenious Bonniksen measuring-apparatus, known as the "dilatometer," these qualities can be quickly and readily determined. Expansions as small as $\frac{1}{10,000}$ inch on a length of 1¼ inch are read in a few seconds, and an arrangement of the apparatus enables this to be determined upon specimens at temperatures varying between that of liquid-air and several hundred degrees Centigrade.

As research on this subject is at present in progress no definite conclusions can be drawn, but Guillaume in France has discovered that a nickel-iron alloy containing 36 per cent. nickel has the very small coefficient of 0·0000015 as compared with 0·000011 for ordinary steel.

X.—Conclusion.

In concluding these remarks it will not be difficult for my audience to understand how impossible it is to convey in a brief address like the present an adequate idea either of the immense development of the modern metallurgy of iron and steel or of the problems met with on the manufacturing side. No industry has progressed in greater ratio, and looking forward to the future it can be safely said that

apart from some cataclysm unforeseen by any human eye, this progress is bound to continue, so that by the end of the first half of the present century the annual output of iron will almost certainly be not far short of the startling figure I recently mentioned in a Presidential Address, namely, 100,000,000 tons.

The scientific side of metallurgy is always advancing, so that by the combined aid of science and practice we may confidently look forward to the metal iron, with which I have to-night tried to deal, continually proving of increasing benefit to mankind.

Finally, as Lord Rayleigh has aptly said, progress is not so much a matter of acquiring scientific knowledge as of getting imbued with the scientific spirit. It is this which will enable us to deal satisfactorily with our unsolved problems.

The PRESIDENT said he was sure the members had listened with the greatest pleasure to Mr. Hadfield's elucidation of one of those departments of the engineering profession which, before all others, was an increasing necessity of the age in which they lived. They had been able during the course of the lecture to anticipate a still further pleasure, namely, being witnesses of those demonstrations which the lecturer was about to give in the Reading-Room. He had the greatest pleasure in moving a vote of thanks to their colleague for the excellent manner in which he had delivered his lecture.

Mr. CHARLES HAWKSLEY, Past-President, said that, as the most "ancient" Past-President at that meeting, he had been called upon to second the motion which had been proposed by the President, a motion which he felt really needed no seconding, and which would receive the hearty sanction of all present. The lecture had been a most interesting one, and they could only regret that it had had to be so much shortened in order that they might enjoy the demonstrations which were to follow, and from which he would not detain the members by any further remarks, except to say that he thought the lecturer had shown the true spirit of the investigator, inasmuch as he had expressed very fully his sense of how much there was yet to learn, and how they ought to look to doing something in the future to investigate the problems still left to be unfolded. He had great pleasure in seconding the motion.

The motion was then put and carried by acclamation.

Mr. R. A. HADFIELD, in acknowledging the vote of thanks, said that the preparation of the lecture had been a labour of love. He desired to say how very much he was indebted to his own assistants, who had worked so hard to get things in order for the demonstration

in the Reading-Room. No one man could do a work of that kind alone, and he therefore had very great pleasure in acknowledging the assistance of his eight or ten collaborators, who had come up from Sheffield that evening to do their best to help him.

The demonstrations and exhibits referred to in the lecture were subsequently inspected in the Reading-Room. A list of the exhibits is given in the following Appendix.

[APPENDIX.

APPENDIX.

List of Exhibits.

1. *Literature and Portraits.*—A collection of Metallurgical Literature, dating from about the end of the fifteenth century to the present time; also Portraits of about fifty workers in scientific metallurgy, dating from early to recent times.

Old Russian Steel Work.

A collection of historic interest, lent by Messrs. F. and H. Huntsman, comprising:—

Portrait of Huntsman (about 1780).

A Grandfather's Clock, made by Benjamin Huntsman. The springs, pendulum, etc., in this clock contain his first successful results in the manufacture of Crucible Cast Steel.

Fragments of Ingots. These probably represent some of Huntsman's earliest attempts. The exact date is not known, but there is no doubt they were made before the year 1800.

B. Huntsman's Ledger, with entries from 1785. This is of interest as showing methods of business in early days.

2. *Alloys and Special Steels.*—Brittle Iron-Manganese Alloy, containing 4½ per cent. manganese.

Art Castings in manganese steel and cast iron.

"Resista."—Iron 79 per cent.; nickel, 15 per cent.; manganese, 6 per cent., alloy. A 2½-inch cast bar is shown bent double cold. In its forged condition the material has a tenacity of about 60 tons per square inch, with elongation of 60 per cent. to 70 per cent. This alloy is not embrittled by liquid-air.

"Inert."—A non-magnetic cast-iron alloy, which is machinable.

Pyrophoric Material.—An alloy of iron containing 30 per cent. cerium, and other rare metals.

Magnetic alloy of copper, 60 per cent., manganese, 25 per cent., and aluminium, 15 per cent., in which neither iron, nickel, nor cobalt are present.

Specimens of various elements contained in steel and iron alloys.

3. *Chemical Laboratory Apparatus.*—Estimation of carbon in iron and steel by combustion. The apparatus consists of a muffle-furnace, capable of heating four tubes at the same time, and in addition to the ordinary drying and purifying train, has a specially convenient form of absorption-bulb.

Method of stirring solutions by means of an air-blast. The air is freed from solid particles by passing it through a layer of cotton-wool and then through a layer of asbestos.

Chemical balance capable of weighing to one-tenth of a milligramme.

Apparatus for determining sulphur in iron and steel. A determination may be accurately made in 20 minutes to ¾ hour, according to the solubility of the sample.

Solutions of steel dissolved in cold dilute nitric acid, after it has undergone different heat-treatments. The depth of colour is proportional to the amount of hardening carbon in the solution.

4. *Metallography.*—Photo-micrographic outfit for metallurgical work, capable of magnifying metallic sections from 25 to 2,000 diameters. This is specially suitable for photographing at high magnifications.

Microscopes for the examination of metallurgical sections.

Selection of typical steel sections, polished and etched, for examination.

5. *Pyrometry.*—Various types of electrical and optical pyrometers used for controlling temperature.

Apparatus for calibrating.

Apparatus for obtaining heating- and cooling-curves with "induction galvanometer" to show the recalescence and critical points in iron and steel.

Experiments showing the sharply-defined hardening-temperature of steel.

Temperature-chart (*Figs. 1*), showing the range from absolute zero to the estimated temperature of the sun; also the principal melting- and freezing-points on the Centigrade and Fahrenheit scales.

6. (*a*) *Electric Furnaces.*—Laboratory types of electric furnaces for heat-treatment and melting purposes, including nickel-wire tube-furnaces; Kryptol crucible furnace; electric arc melting-furnaces.

(*b*) *Electric and Magnetic Measurements.*—Measurement of conductivity by the "conductometer"; this can also be used for showing the high restivity of "Resista" alloy.

Apparatus for determining permeability curves.

Ewing's hysteresis tester.

7. *Mechanical Tests.*—Tests by impact method on notched specimens, showing toughness or brittleness of steels.

Tests showing hardness of steels or alloys by means of Brinell's ball method.

8. *Liquid Air.*—Experiments showing the effect of liquid air on the properties of metals at a temperature of $-182°$ C.; and upon the "reversibility" and "irreversibility" of various special steels and alloys of iron with nickel, manganese and other elements; also its embrittling effect upon iron and steel.

Collection of specimens and test-bars used in the experiments relating to the effect on the mechanical and other properties of iron and its alloys produced by liquid-air temperatures.

9. *Apparatus for Measuring Coefficient of Expansion.*—The Bonnisken dilatometer, which enables very rapid determinations to be made accurately on small samples over a wide range of temperature. By this method expansions as small as $\frac{1}{10000}$ inch on a length of $1\frac{1}{4}$ inch can be readily measured. This is an exceedingly delicate instrument, the only one yet made. It has a range from $-200°$ C. to $800°$ C.

Sect. II.—OTHER SELECTED PAPERS.

(*Paper No. 3633.*)

"Some Bridge Failures during a Heavy Cyclone in 1905, in Gujerat, India."

By Andrew Thomas, Assoc. M. Inst. C.E.

The province of Gujèrat, in India, during the past 6 years has suffered more or less from drought and famine, the annual rainfall having either failed entirely or been insufficient in quantity. The monsoon of 1905 should have commenced in the early part of June, but up to the 22nd July practically no rain fell. On the evening of that date a cyclone set in, and from the 22nd to the 25th July the rainfall was unprecedentedly heavy. Between the evening of the 22nd and 8 A.M. on the 23rd 7·68 inches of rain fell at Sabarmati and 9·70 inches at Ahmedabad; and between 8 A.M. on the 23rd and 8 A.M. on the 24th 23·11 inches of rain fell at Sabarmati and 13·20 inches at Ahmedabad. The normal rainfall for the whole season is about 30 inches; therefore, in a period of 30 hours the rainfall was equal in amount to the total rainfall which usually extends over a period of 5 months in normal seasons. The country for miles was under water to a depth of 2 to 3 feet, and houses built entirely of sun-dried bricks or burnt brick in mud fell down by hundreds in Ahmedabad and the surrounding villages. In Ahmedabad City the damage to grain and sugar stores amounted to about £33,000.

The path of the storm and the damage done to the railway-lines are indicated in the sketch-map shown in Fig. 1, Plate 3.

The cyclone began at Wadhwan, breaching the railway-line very badly for a length of 250 feet. On the night of the 22nd July the Ahmedabad-Dholka Railway was breached in many places, and on the morning of the 23rd July it was considered unsafe to allow trains to pass over the Ranip Bridge, on the Rajputana-Malwa Railway near Sabarmati. Sabarmati is the southern terminus of that railway and its junction with the Bombay-Baroda and Central India Railway. The Ranip Nala is a small dry nala which in years of ordinary rainfall

carries a flood of 3 to 5 feet only during the monsoons; the Rajputana-Malwa Railway (metre gauge) crossed it on a girder-bridge of 60 feet span, and the Bombay-Baroda and Central India Railway (broad gauge) crossed it 200 feet lower down the stream, also on a 60-foot girder-bridge. By midday on the 23rd July the bank behind the north abutment of the broad-gauge railway-bridge had been breached, and a short time afterwards the north abutment of the metre-gauge bridge fell, carrying the girder with it. About the same time two other bridges less than ¼ mile away fell; one of these was a 20-foot arch on the Ahmedabad-Dholka Railway and the other a 20-foot girder-bridge on the broad-gauge line to Viramgam. A 20-foot arch on the Rajputana-Malwa Railway at the same point was also badly damaged. These three bridges were within 100 yards of one another, crossing the same stream, the Rajputana-Malwa railway-bridge being on the up-stream side, Fig. 2, Plate 3. On the same date a 20-foot girder-bridge on the Ahmedabad-Prantij Railway, and 6 miles from the scene of the accident just described, was carried away; the brick masonry was broken up and carried several hundred feet downstream, the girders being left suspended from the rails over the breach. The Kalol Vijapur and the Kalol Kadi branches escaped with a few breaches in the banks, as also did the Mehsana Kheralu branch; the main-line bridge, of three 40-foot girder-spans, on the Rajputana-Malwa Railway, north of Mehsana, sustained a very heavy flood on the morning of the 24th July, and, but for the energetic measures taken immediately to repair the threatened breach, would have been carried away. The abutments were pier-abutments, surrounded by an apron of pitching composed of concrete laid in bags side by side. This apron was carried away, together with all the earth around the front of the pier-abutment, and the water was sapping the earth behind the abutment, and had nearly cut its way through the bank. By throwing stone-pitching, sand-bags, and branches of trees into the breach, the abutment was saved from destruction. The foundations of this bridge were very badly scoured, and it has had to be rebuilt.

On the morning of the 24th July, the Patan branch was very severely damaged; a single-span 40-foot girder-bridge near Mehsana had the earth behind both abutments carried away. The abutments were of the box-type, with the earth-slopes around them running below high flood-level; these slopes were too steep, and were carried away, causing the bank to slip behind the abutments; the channel was badly scoured out, and the foundations were threatened. Stone-pitching, bags filled with bricks, and branches of trees, were thrown in to save the foundations. Between Patan and Mehsana the

railway-bank was breached in eighteen places, some of the breaches being large. Two bridges were more or less damaged, and a girder bridge of two 20-foot spans was undermined to a depth of 25 feet the abutments, pier, and girders falling into the hole thus formed and remaining invisible for many weeks; a diversion had to be made to carry the traffic round this bridge.

The extent of all these damages was so great that the energies of the engineering staff were taxed to the utmost to restore communication. The branch-lines had to be closed to traffic for a week for necessary repairs, but as only two passenger-trains run on the branches daily and as all business was practically suspended owing to the floods, the public were not seriously inconvenienced. The most serious delays to traffic were caused by the carrying away of the Ranip Bridge near Sabarmati, as this bridge was on the main-line of the Rajputana-Malwa Railway. On the 23rd July, at midday, the bridge collapsed, and rain continued to fall heavily and incessantly all that day and night; the whole country was flooded, and labour could not be obtained. On the morning of the 24th July an attempt was made to throw a temporary foot-bridge over the stream, and by the evening, the floods having partially subsided, it was successfully completed and mails and passengers were taken across it; all goods-traffic was cancelled. On the morning of the 25th July a diversion was laid out, and the construction of a temporary bridge was commenced. The only materials available for this work were sleepers, broad-gauge rails weighing 60 lbs. to the yard, and three spans of old broad-gauge 20-foot girders. The sleepers were made up into cribs, laid on platforms of sleepers, and half-filled with rubble; on each side of the cribs were built rail-trestles, connected together by long bolts; the raking-struts were boarded to the uprights with vertical sleepers, and the spaces between these were filled with stone, forming stone cutwaters, the platforms having been extended to the ends of the rail-trestles, Figs. 3, Plate 3.

This bridge was completed on the evening of the 30th July, or in 6 days; the bridge has stood the wear and tear of heavy traffic for a period of 6 months, and is still in good order. The steepest gradient on the diversion is 1 in 75, and the sharpest curve has a radius of 600 feet. All trains stop dead at the head of the diversion, and run over it at 5 miles an hour. Passenger-trains run over without assistance, but all goods-trains have to be piloted over. It was found that the heaviest type of engine could only just pull a full load across, but as the strain on the engine was very great, and failures were likely to occur, causing considerable delay to traffic, it was decided to pilot all goods-trains across.

The broad-gauge railway-bridge over the Ranip Nala consisted of a 60-foot plate-girder span on screw-piles, three piles to each abutment, braced horizontally and diagonally up to the level of the girder-bed with earth-slopes falling around the piles, the lower portion of the slopes being pitched. In addition, the waterway had been further restricted by building a retaining-wall, leaving an opening of about 10 feet only, and for 30 years no serious trouble had been experienced. This bridge was built a little further south than, and not directly opposite, the Rajputana-Malwa railway-bridge, so that the water in high flood through the latter was directed against the bank behind the north abutment of the broad-gauge bridge, and eventually carried it away, together with all the pitching on the slopes, leaving the screw-piles standing with the girders in position on them intact.

The Rajputana-Malwa railway-bridge was a single 54-foot span of Warren girders of the old broad-gauge type, with pin-connections, the roadway being supported on the top booms. The abutments were of brickwork, 14 feet 6 inches in width and 12 feet 6 inches in length, each built on a single well 12 feet 6 inches in external diameter; these wells were sunk into the sandy bed of the nala to a depth of 15 feet below the bed. The superstructure was 20 feet above bed-level, and its width being greater than the diameter of the wells it was top-heavy. The brickwork of the wells was 3 feet 6 inches in thickness and was laid on wooden curbs; the wells were plugged at the bottom with concrete 6 feet in thickness, the remainder being filled with sand. The earth-slope around the abutments was protected, over the whole area of the slope, by a concrete facing 2 feet in thickness, plastered smooth. This concrete was undermined by the floods and fell, breaking up into large blocks. The flood rose to a height of 15 feet above bed-level, or half-way up the girders, and there is no doubt that scour was going on around the well of the north abutment. The broad-gauge bridge being constricted in area, water was headed up about the Rajputana-Malwa railway-bridge and the broad-gauge railway-bank until the latter gave way; the sudden release of the water so headed-up increased the scour around the well of the north abutment, undermining the abutment and causing it to fall downstream, carrying the girder with it; the south end-standards of the girder remained on their abutment. In falling, the north end made a complete turn, and the girder lay with its bottom upwards, having been also slightly twisted. This bridge had stood for 30 years, and during that period no flood higher than 5 feet had ever been experienced. The construction of the bridge is shown in Figs. 4, Plate 3.

The 20-foot arch-bridges on the Ahmedabad-Dholka Railway, and the 20-foot girder-bridge on the Viramgam branch of the broad-gauge railway, were carried away, probably owing to their having no flooring and no curtain-walls, and although the foundations were about 9 feet below bed-level the abutments were undermined and fell. The 20-foot arch-bridge on the Rajputana-Malwa Railway, which had a brick invert and curtain-walls, was only 100 feet away, and the body of this bridge was not damaged, although the wings, which were not protected, were undermined at the newels and partly fell in.

These failures show that shallow wells are not safe, and that single wells are not suitable for the foundations of abutments. Shortening the abutments and running the earth-slope into the span is also inadvisable, as no pitching or any other kind of protection will save the slopes in such a situation in heavy floods. All culverts in a country subject to heavy floods should have curtain-walls on the downstream side, from newel to newel, reaching in depth to 2 feet below the bottom of the foundations. On the upstream side, a low drop-wall, from newel to newel, say 3 feet below the top of the flooring, is sufficient to keep the water from getting under the flooring. The whole area between these drop-walls should be floored with 1 foot thickness of concrete and 9 inches thickness of stone on edge, set in mortar. This forms an efficient protection over the whole area of the culvert. Pier-abutments are not suitable when exposed to heavy floods; they should be employed only when they can be placed on high ground above flood-level. Box-abutments also are not suitable for streams liable to heavy floods unless they can be placed on high ground above all ordinary floods. The experience gained from this cyclone shows that the earth-slopes around the box-wings get washed away, causing the earth to slip from under the rails behind the ends of the wings, making the road unsafe for traffic.

The Paper is accompanied by three tracings, from which Plate 3 has been prepared; and by three photographs, which may be seen in the Library of the Institution.

(*Paper No. 3635.*)

"The Midland Railway Company's Harbour at Heysham, Lancashire."

By George Neill Abernethy, M. Inst. C.E.

Towards the end of the year 1891, the late Mr. James Abernethy, Past-President Inst. C.E., was consulted by the Midland Railway Company as to the construction of a dock at Heysham, in Morecambe Bay, in connection with their railway system, and in his preliminary and subsequent reports was assisted by the Author, then in partnership with him. The Midland Railway Company had for years experienced difficulty, and were incurring considerable expense, in maintaining their existing pier- and harbour-accommodation at Morecambe, where it was only possible for steamers and vessels to enter and leave the harbour near the period of high-water; moreover, the channel leading to Morecambe was difficult of navigation. Mr. Abernethy was impressed with the natural advantages which the proposed site afforded, as being in close proximity to Heysham Lake, a deep-water channel having a depth of 40 feet at low-water of ordinary spring-tides.

The scheme first proposed was a dock of some 30 acres in area, with a lock and entrance, situated in much the same position as the present breakwater-heads; but in 1895, after further consideration of the project with the Company's Engineer, the late Mr. J. Allen McDonald, M. Inst. C.E., it was decided, in view of the particular nature of the traffic to be dealt with, to alter the design to that of a tidal harbour, the site being inclosed by embankments practically in the position indicated on the general plan, Fig. 1, Plate 4.

In 1896 the Midland Railway Company obtained an Act for the construction of the harbour. In March of that year Mr. James Abernethy died, and the Author was appointed by the Midland Railway Company Joint Engineer with the late Mr. J. Allen McDonald, the Company's Chief Engineer. The preparation of the detailed plans was at once commenced, and in July 1897 the contract

was put out to tender and was let to Messrs. Price and Wills, of Westminster.

The first work undertaken was the construction of two embankments, or breakwaters, Nos. 1 and 2, to inclose and reclaim the site of the harbour; the material for these embankments, composed of fairly soft sandstone rock, with some clay and shaley marl, was obtained from Heysham banks, the high ground immediately adjoining the site of the works. The progress of these embankments was at first slow, owing to the difficulty of obtaining the material in sufficient quantity and of getting a good face on the rock, and also owing to the fact that at high-water the face of the cliff was washed by the tide. In constructing the embankments, a trench was first cut in the sand and filled with sandstone rock to form a toe, and to prevent erosion by the sea; two rock-tips were then started on each embankment, the space between the tips being filled with clay and marl; but later on, and after getting farther seaward, it was found better and more expeditious to tip a single rock-bank from two lines of rails, and to side-tip the clay and marl on the inner face. Provision had also to be made for protecting the heads of these tips during stormy weather by keeping in reserve a set of wagons filled with stone; with the aid of these wagons damage to the rock-tips during the construction of the works was almost entirely prevented. The area inclosed by the embankments is 150 acres, and being all on tidal land, with a range of tide of about 20 feet, provision had to be made for the ebb and flow of the tide as the tips approached each other. This was effected by the construction of a timber viaduct having a clear opening of 300 feet, at a distance of 2,300 feet from the Near Naze, this point being selected as being the most sheltered. A temporary dam of clay, with a heavy rough rock facing, was tipped across the site of the entrance, a 6-foot pipe with sluice-valves being laid through the dam for draining the area when finally closed. When the embankments were completed and consolidated, the space left under the timber viaduct was closed by successive horizontal layers of rock and clay until high-water of neap-tides was reached, after which the space was tipped up to the full height of the embankment as rapidly as possible and the water was drawn off from the inclosed area through the sluice-pipe in the temporary dam. These precautions proved effectual, and by April 1899 the sea had been entirely excluded from the inclosed area. For drainage purposes during the progress of the works, the contractors excavated a sump in the sandstone rock at the eastern end of the harbour, and erected two rocker-pumps. The water was conducted from these pumps by shoots and discharged over embankment No. 2. Little

ficulty was experienced in dealing with the water, and the site mained remarkably dry throughout.

Excavation in the harbour was then commenced, the material ken out being used for completing the embankments to their ished width. In the first instance they were 30 feet in width at e top, and the material was side-tipped until a width of 600 feet the root and 170 feet at the ends was obtained. It was then und advisable to heighten the outer embankment from 10 feet to feet above high-water of ordinary spring-tides as a further otection against storms and extraordinarily high tides. The iginal proposal was for a depth of water within the harbour of feet below low-water of ordinary spring-tides, but subsequently is was increased to 14 feet.

The harbour-works consist of a South quay 1,600 feet in length, North quay 900 feet in length, and a fish-stage 300 feet in length. The east end of the harbour is in the solid rock, finished with a 3-to-1 slope, and that portion between the end of the North quay and the seaward end of the embankment is a tipped rock-slope with a hand-packed rough rubble face. The original contract-plans comprised the construction of a wharf, 600 feet in length, on the inner face of embankment No. 3, and a central pier, 900 feet by 150 feet, to accommodate the passenger-service, but after much consideration by the traffic department this central pier was abandoned and provision for the passenger-traffic was made by increasing the length of the quay at embankment No. 3, and by the construction of the North quay. It was originally intended that the foundations of the walls should be put in by means of timbered trenches, but shortly after the harbour excavation was commenced it was found that the material stood with such a steep face that it was possible to include the foundations of the South and North quays in the harbour excavation, and to dispense with timbered trenches. The walls are constructed of 7-to-1 Portland-cement concrete with a 12-inch face of 5-to-1 concrete, the material used being fine ballast from Walney Island and selected stone from Heysham banks. In the larger sections of the walls, sandstone plums were placed, precautions being taken to ensure each plum being sufficiently surrounded with concrete. All the walls have a coping of granite.

South Quay, on Embankment No. 1.—As this quay was intended to be used for the passenger- and cattle-traffic from Ireland, and for the Isle of Man steamers, provision had to be made for landing conveniently at any state of the tide, the rise and fall of which is 27 feet, and as at this time there had been a change in the Managership

of the Company, which involved some alterations in the traffic requirements, openings were left in the wall at intervals to provide for the subsequent construction of the passenger- and cattle-subways. A heavy timber staging was constructed along the whole face of the quay, with continuous landings to give access from the steamers to the subways, and also to take the impact of steamers coming alongside and to minimize the risk of damage either to them or to the wall itself. The staging was constructed of pitch-pine piles, 12 inches by 12 inches, with front fenders of Karri timber, the whole being tied by diagonal and cross bracing, and secured to wrought-iron brackets previously built into the wall. The foot of each upright rests in a cast-iron socket built into the concrete toe of the wall; the whole staging is well and thoroughly tied back into the wharf by long bolts securing the wrought-iron brackets on which the cross-timbers rest. In view of future extension as the traffic develops, it was decided to construct a lock-entrance, 80 feet in width, with a caisson-sill and sluices, immediately beyond the end of the South quay, with a quay-wall, now called the west wall, extending up to the end of roundhead No. 1. This entrance has been closed by a temporary dam. Beyond the South quay the sandstone rock dipped rapidly, and the whole of the west wall foundations had to be constructed in timbered trenches.

North Quay, on Embankment No. 2.—On the opposite side of the harbour the North quay was constructed. This quay being almost exclusively used for goods from Cork and from Scotland, it was not thought necessary to provide extensive accommodation for passengers, and accordingly the front staging was dispensed with, and Karri fender-piles were bolted to the face of the quay for steamers to lie against. A single subway for passengers was provided, to afford convenient access at about half-tide level.

Roundheads.—Simultaneously with the formation of these wharves, the construction of two roundheads was commenced. From the result of the borings which had been taken, it was supposed that the clay strata met with at a depth of 10 feet below the harbour-bottom was sufficiently good to form a secure foundation; accordingly the whole area of these heads and wing-walls was inclosed by close timber piling, and excavation was started inside. It was found, after going to a depth of 20 feet, that it was impossible to carry out this work as originally intended, the running sand and silt rising up in the bottom of the trench as fast as it could be taken out; it was therefore decided to sink monoliths, and one of these was accordingly put down at roundhead No. 1; this monolith was 17 feet in width by 24 feet in length, and was built of concrete on a steel shoe. The

steel shoe was constructed by Messrs. Handyside and Company, of Derby, and weighed 8 tons. The sinking of this monolith was effected without much difficulty by excavating with a Priestman grab and by hand-labour inside; when the solid rock was reached the bottom was concreted up for a thickness of 12 feet, and the remaining portion was filled with sand to within 8 feet of the top, when concrete was again employed. It had been intended to sink a number of these monoliths, side by side, over the whole area of the roundhead, but owing to the satisfactory manner in which the first had gone down it was decided to form each roundhead of a single circular monolith. These were the largest monoliths which had ever been used, and were constructed in the following manner:—

A steel shoe was first built up of plates, angle-bars and tee-bars, stiffened at a height of 3 feet 3 inches above the cutting-edge by gusset-plates and angle-bars; the shoe was 55 feet in diameter over the skin-plates, the circumferential sections being 8 feet in depth and 8 feet in width at the top. Owing to the great weight which this shoe had to carry, special gusset-plates and angle-bars were used for stiffening the cutting-edge, with intermediate stiffeners of lighter scantling between the main bays, which were spaced 4 feet apart. The outer edge of the shoe was plated for a depth of 3 feet 3 inches; the remainder, after being shuttered externally, was filled with 3-to-1 concrete preparatory to sinking. Brickwork in 2-to-1 cement-mortar was then built on the shoe, this being found more convenient and more expeditious than concrete, whilst it also admitted of great weight being brought to bear on any particular part of the monolith where found necessary. As the brickwork proceeded, the material (generally sand) was excavated from the interior partly by grabs but chiefly by manual labour, as it was found, especially at the greater depth, that the sand was too hard for the grab to grip properly. The monoliths are divided into four divisions or compartments by internal cross-walls, carried on girders attached to the upper portion of the steel shoe at such a height that men could pass from one compartment to the other. Pumps were kept working in each compartment. Rock was reached at a depth of 42 feet 6 inches below the level of the harbour-bottom, the total depth sunk through the sand being 75 feet. The lower portion of the monolith was then sealed with 6-to-1 concrete to a height of about 15 feet, after which sand was employed to fill the interior up to the level of the harbour bottom. A topping of 13 feet of concrete was then added, and on this the upper portion of the roundhead was constructed, of 6-to-1 concrete within shuttering. These circular monoliths are 55 feet in diameter and 75 feet in depth, the weight of the steelwork being 73

tons, and the total weight of the monolith, with the brickwork completed, 6,000 tons. It was found that when this large monolith had been sunk to the rock it was only 5 inches out of the perpendicular, and that sunk on the site of roundhead No. 2 was almost equally satisfactory.

Temporary Lighting.—On the commencement of the works, two temporary timber dolphins were erected at the low-water line of the entrance-channel for the purpose of lighting, as required by the Trinity Board. On the completion of the works these dolphins were removed and a Pintsch gas-buoy, to burn for 3 months, was placed on the side of the south dolphin.

Lighthouses.—A lighthouse has been erected on the southern roundhead, not only to indicate the entrance to the harbour, but also to guide vessels up Heysham Lake, and for this purpose a leading lighthouse has been placed on the Near Naze. The lighthouse on the roundhead is constructed of cast-iron plates $\frac{7}{8}$ inch in thickness; the focal plane of the optical apparatus is 16 feet $4\frac{3}{4}$ inches above the surface of the roundhead, and 30 feet 4 inches above high-water of ordinary spring-tides. The tower is 6 feet 10 inches in diameter at the top, and 8 feet 11 inches at the base. An outer gallery is fixed on cast-iron brackets and provided with a balcony. The lantern-floor consists of chequered iron plates supported on rolled steel joists. The tower is secured by sixteen holding-down bolts, $1\frac{1}{2}$ inch in diameter by 6 feet in length, with cast-iron anchor-plates 12 inches square. The lantern is 6 feet $1\frac{1}{2}$ inch in internal diameter, and consists of a cast-iron pedestal with gun-metal ventilators. The glazing is framed in gun-metal helically-inclined frames. The dome and ball-ventilator are of copper. The illuminating apparatus consists of a fixed dioptric lens showing over an arc of 360°, with a vertical aperture of 80°. The illuminant is gas, with a two-wick capillary oil-burner as a stand-by. The leading light on the Near Naze is carried on an openwork structure giving a height of 46 feet from the level of the concrete base, and a height of 66 feet 6 inches from high-water to the focal plane of the optical apparatus. The concrete base for the structure is built on the Naze Rocks, and the tower is built into this base to a depth of 10 feet. The structure consists of four solid iron columns, 5 inches in diameter, with cast-steel connecting-sockets. The horizontal rolled-joist bracings are connected to the columns and steel sockets by wrought-iron straps. The diagonal bracing is of round iron with screw-couplings. The lantern floor, intermediate landings, and ladders are of wrought iron. The lantern is 5 feet in diameter, and consists of a mild steel pedestal, copper roof and ventilator. The illuminating apparatus

consists of a holophote, with a refracting lens of 80° vertical and horizontal angle, with two reflecting prisms on the outside. The illuminant is gas, and the storage gas-holders are on the concrete foundation. The angle of illumination given by the lens is 8½°, which acts as a leading light in connection with the light on the roundhead. The lighthouses were supplied and erected by Messrs. Chance Brothers, of Birmingham.

Passenger-Station and Goods-Sheds.—The passenger-station has an island-platform, 600 feet in length and 47 feet in width, with a line of rails on each side, within the building; the platform is covered for a length of 450 feet, the roof being 75 feet in width. A suite of waiting- and refreshment-rooms has been constructed along the centre of the platform. For the convenience of passengers, luggage-hoists have been provided from each of the landing-stages, at various levels to suit the state of the tide. As the sheds for the arrangement of goods for transit are situated close to the quay, with the passenger-station beyond, overhead gangways have been constructed across the goods-sheds into the passenger-station, and the stairways from each landing-stage, as well as the hoists, communicate directly with this overhead gangway. Passengers will thus be completely protected from the weather.

The goods-station is nearest to the quay, and has a length of 500 feet, there being ground available for a further extension of 100 feet. A second goods-shed has been constructed, having a length of 175 feet. The distance between the buildings and the front edge of the quay is 27 feet 6 inches, which is sufficient for the working of large cranes. The crane-legs on one side travel on rails laid on the quay, and those on the other side on rails supported on the stanchions of the goods-station. The rolling-stock of the Midland Railway can easily pass along the quays under the cranes, the width between the centres of the crane-rails being 31 feet 2 inches.

In connection with the design of the buildings, serious consideration had to be given to the question of wind-pressure, as the harbour is exposed to south-westerly gales. An anemometer-tower was erected on the Near Naze, with complete apparatus for taking records, including a Beckley anemometer. This instrument, on the 26th February, 1903, when a train was blown off the Leven Viaduct on the opposite shore of Morecambe Bay, recorded a velocity of 100 miles an hour. It was decided to construct the buildings of steel framing with wooden boarding and with an exceptionally flat roof, the rise being 6 feet 6 inches, equal to about 1 in 2. It was also deemed important to limit the load on the foundations. So far as roofs and walls are concerned there is little difference between the

goods- and passenger-stations. The span of the goods-station is 59 feet, and of the passenger-station 75 feet. The whole of the framework of the goods-station is carried on steel stanchions. These stanchions are founded on concrete carried to a depth of 21 feet below quay-level. Each foundation consists of a block of concrete, 11 feet by 4 feet, with base-plates, and four 1¼-inch lewis-bolts for holding down the foundation-girder of the stanchions, which is 7 feet in length and is built of plates 12 inches in depth, with 12-inch flanges. To this base-girder are riveted the vertical members forming the stanchions, so arranged that the width at the base is 6 feet, tapering to 18 inches just below quay-level. Above this the stanchion continues 18 inches in width to the top. On the top of each stanchion is a bracket, to which is secured the continuous longitudinal girder supporting the rails on which the wheels on one side of the gantry-crane run, the wheels on the other side travelling on rails on the quay. Between the stanchions there is steel bracing carrying timbers forming the side of the building. The stanchions carry the transverse girders supporting the roof-principals. These girders are 59 feet in length over all and are of the ordinary lattice-type, 4 feet in depth. The wind-bracing is specially strong, there being 1¼-inch diagonal tie-rods with screw-couplings through each girder. The girders are spaced at intervals of 25 feet, which fixed the span of the roof-principals. These are transverse to the line of the main girders and therefore parallel to the longitudinal line of the shed. There are six principals to the width of the building to each span. They are of simple construction, being built of tee-bars and tie-rods. The covering over the good-sheds is entirely of zinc, but the central part of each span in the passenger-station roof is glazed, and the side parts are of zinc. The end of the glazing over-laps the zinc at a height of 1 foot to provide ventilation, a suitable lip-covering being arranged to prevent the rain driving into the interior.

Entrance-Channel.—After the water was admitted into the harbour, the temporary dam at the entrance had to be removed; the upper portion was taken away by means of grabs and steam-cranes, and when the water in the harbour had reached sea-level the work was continued by dredging. The entrance-channel was then dredged to a depth of 17 feet at low-water of ordinary spring-tides, extending from the harbour to the low-water line in Heysham Lake. In forming this entrance-channel 1,115,148 cubic yards of material were removed, the plant used being two bucket-ladder dredgers; two sand-pumps, the capacity of each hopper being 500 cubic yards; two steam-hoppers, each of 500 cubic yards capacity; and two dumb-hoppers, each of 250 cubic yards capacity.

Contractors' Accommodation for the Workmen.—At the time the works were commenced Heysham was a small village, inhabited only by a few agriculturists, so that the contractors had to make arrangements for the accommodation of their workmen. They accordingly constructed a village of huts, known by the name of "Klondyke," consisting of three large huts, each accommodating seventy-five men; forty-five small huts, each taking a hut-keeper and his family, and twelve men; a canteen and recreation-room, 90 feet in length by 60 feet in width; butcher's, baker's, clothier's, and barber's shops; a police office, etc.; as well as a special bakery capable of supplying six hundred loaves per day, and a large café where, besides the usual groceries, hot meals were served to the men. All the buildings, with the exception of the huts, were lighted by acetylene gas. When in full swing there were about seven hundred men living at this settlement. In addition to the foregoing, an enterprising resident in the neighbourhood erected a collection of huts further inland, which was distinguished by the name of "Dawson City."

Contractors' Workshops and Plant.—A list of the workshops erected by the contractors on the site, and of the machinery employed in carrying out the works, is given in the Appendix.

Mond-Gas Electric Power Installation.—Electricity is employed for practically all the machinery. Not only is it claimed that electricity effects considerable economies in working as compared with hydraulic and steam-power for the actuation of the cranes, capstans, lifts, pumps, etc., which constitute the bulk of the power-using machinery in harbour-works, but it imparts an elasticity to the power-distribution scheme otherwise unobtainable. Where extensions are probable this consideration naturally has much weight, and no doubt it did much to influence the Midland Railway Company in favour of the motor drive. Mond-gas is used for the engines and is generated in a producer-plant constructed by the Power Gas Corporation, Limited. The air-blast for producing the gas is delivered by a Roots blower, or in cases of emergency by a Körting blower, and after passing along the air-main enters at the bottom of the air-tower. In this tower the air comes into intimate contact with the water, which has been heated by the gas cooling-tower, and is thereby saturated with water-vapour at the temperature at which it leaves the latter. The air-tower is packed with circular earthenware tiles down which the water trickles, meeting the air as it rises to the top. It leaves the air-tower at the outlet and after passing along the air-drain, where it receives a further supply of steam from the exhaust of the engine driving the auxiliary

machinery, it enters the external pipe of the superheater. The superheater consists of two legs, each having an internal and an external pipe; the hot blast passes through the annular space between the two pipes, and is therein superheated by means of the hot gas which is passing in the opposite direction from the producer through the internal pipe of the superheater. The superheater blast then enters the producer. The producer is cylindrical in shape, and consists of an external and an internal wrought-iron shell. The internal shell is lined with fire-brick as far down as the fire-box and has the shape of an inverted cone at the bottom; the external shell, however, is cylindrical down to the water-seal, where it is luted with water. In the upper part of the producer, immediately beneath the fuel-hopper, is an internal bell, which, being kept full of fuel, automatically maintains the proper height of fuel in the body of the producer, and thus assists in maintaining uniformity in the composition of the gas. The bell further obviates the serious fluctuation in pressure throughout the plant which would be brought about if the fuel were dropped straight into the producer, and by providing for partial distillation of the "green" fuel before it enters the main body of the producer, reduces, to some extent, the amount of tar formed. Each producer is further provided with four poke-holes for poking into the interior of the bell. A circular platform is provided for working the coal feeding-apparatus and the poke-holes. The blast entering the producer from the superheater passes all round the annular space between the internal and external shells and enters the interior at the bottom. The resultant gas, under ordinary circumstances, when working on a good load and consuming suitable Nottinghamshire or Lancashire slack, will have approximately the following composition:—

Carbonic acid (CO_2)	12 per cent.
Carbonic oxide (CO)	17 ,, ,,
Hydrogen (H)	21 ,, ,,
Marsh gas (CH_4)	2 ,, ,,
Nitrogen (N)	48 ,, ,,
	100

The gas, having deposited a great part of its suspended dust in the superheaters, enters the collecting-main, where more dust is separated, being removed daily from the dust-boxes provided at the bottom. From the collecting-main the gas passes into the washer, rectangular in shape, in which revolves a dasher fitted with blades which throw fine spray into the gas as it passes through. The remainder of the dust in the gas is thus thrown out and deposited in the water. The

dust which sinks to the bottom of the water may be removed, while the plant is working, by means of rakes and scoops provided for the purpose. From the washer the gas enters the bottom of the gas-cooling tower. The gas passing up the tower comes into intimate contact, on the way, with water trickling down, and gives up its heat to the cooling-water, which is then pumped to the heating-tower, in which it is cooled by the incoming air. From the cooling-tower the gas passes to the gas-holder. After leaving the holder the gas enters a fan in which it is dashed with great force against the sides, and the remaining tar is thus thrown out. The fan forces the gas through a sawdust scrubber which is packed with coarse shavings and sawdust. In this apparatus the remaining particles of tar are removed, and the gas is left in a pure condition ready for consumption in the engines. The coal used in the producers is bituminous slack. The slack is dumped from railway-wagons directly into the elevator-boot, and is raised by a bucket-conveyor which deposits it in a horizontal spiral conveyor running across the tops of the bunkers above the producers. Each bunker holds 10 tons. The conveyors are driven by a 7½-HP. Westinghouse motor running at 1,850 revolutions per minute. From the scrubber the gas passes into the gas-main, which runs outside the engine-house, alongside the three 250-HP. gas-engines. The engines are of the Westinghouse vertical single-acting pattern, and run at the comparatively high speed of 200 revolutions per minute. Each gas-engine is direct-coupled to a 150-kilowatt continuous-current generator of standard Westinghouse pattern, giving a current of 325 amperes at 430 to 460 volts when working at normal speed. The storage-battery consists of two sets, each of 115 cells. Each cell has a minimum capacity of 180 amperes for 6 hours, with a final voltage of 1·85 volt.

Lighting.—The landing-stages, passenger-station, goods-sheds, cart-roads, sidings, engine-house, etc., are lighted by one hundred and six 4-ampere Jandus arc-lamps, each fitted with raising- and lowering-gear, and the equivalent of one thousand 16-candle-power incandescent lamps. The lighting of the quay-side is effected by means of two-light fittings run on alternate circuits and carried in lanterns on 10-foot cast-iron pillars, spaced about 60 feet apart.

Water-Supply.—Water is obtained from an Artesian well by means of a pump made by Messrs. Timmins. The pump-head well is 8 feet in internal diameter, is sunk to a depth of 16 feet 6 inches below the surface, and is lined with cast-iron segmental tubing. A cast-iron stand-pipe of 26 inches bore, with a large body-flange, is fitted at the base of the well and carried down 22 feet 6 inches below the surface; this and the well-bottom are made tight with concrete to prevent any

surface-pollution percolating into the bore-hole. Below the stand-pipe, to a depth of 101 feet, the bore-hole is 24 inches in diameter, and is lined with 19-inch and 21-inch cast-iron flush-jointed lining-tubes. The annulus outside the tubes is grouted with cement, sealing the bore-hole to the base of the tubes in order to obtain the pure and deep-seated Artesian-well water. From this point downwards an 18-inch open bore is continued to a depth of about 350 feet below the surface. The bore-hole pump is 11 inches in diameter, of the combined ram and bucket type, the base of the suction being fixed at 125 feet below the surface. The pump is capable of delivering 288,000 gallons of water per day through a 6-inch main 1,550 yards in length into a reservoir of 392,850 gallons capacity, 38 feet above the rail-level of the harbour.

Cranes, Capstans, etc.—The cranes and capstans have been supplied by Messrs. Stothert and Pitt, of Bath, and electrically-equipped by the British Westinghouse Company. There are six 5-ton wharf-cranes, one 2-ton wharf-crane, six 30-cwt. platform-cranes in the goods-sheds, ten 1-ton capstans, and two 3-ton capstans. Two sets of Merryweather fire-pumps, having a united capacity of 1,400 gallons per minute, are installed, and two Waywood lifts are provided to take passengers and goods to and from the upper and lower landing-stages.

The harbour is designed to provide increased accommodation for goods- and passenger-traffic to Ireland, and for excursion-traffic to the Isle of Man. The Midland Railway Company have built a new fleet of steamers, with every modern convenience, which commenced running in September 1904. In order more effectually to maintain the connections in Ireland, the Midland Railway Company have absorbed the Northern Counties Railway of Ireland and the Donegal line. The intention is to foster the passenger-traffic with the provinces of Ulster and Donegal and to develop the agricultural resources of the country. The harbour is also conveniently situated for railway-connection with the English Midland towns, and a new line has been constructed from the Midland main-line, so that trains run direct viâ Lancaster to the harbour, alongside the steamers. Arrangements have also been made at the harbour for cattle, fish, poultry, and other traffic.

The cost of the harbour-works, without buildings or equipment, has amounted to the sum of £796,619.

The Engineers for the works were the late Mr. J. Allen McDonald, M. Inst. C.E., Chief Engineer to the Midland Railway Company, and the Author.

The Resident Engineer at the commencement of the works was

Mr. Gerald Fitz-Gibbon, M. Inst. C.E., who had had considerable previous experience under the Author in harbour- and dock-works. He left in September 1899 to take up the appointment of Chief Engineer to the Aire and Calder Navigation, and his place was filled by Mr. Baldwin H. Bent., M.A., M. Inst. C.E., who remained until their completion.

The Paper is accompanied by five drawings and two tracings, from a selection of which Plate 4 has been prepared; and by sixteen photographs, which may be seen in the Library of the Institution.

APPENDIX.

CONTRACTORS' WORKSHOPS AND PLANT.

Carpenters' and wagon-repairing shop, 140 feet by 25 feet, in which one foreman and thirty men were employed repairing wagons, hand-carts, trucks, barrows, etc. In connection with this shop ten to fifteen men were employed outside putting up shutters for concreting, sheds and general outside repairs; these were independent of carpenters on permanent work, such as staging, piling, etc.

The cement-shed was 200 feet in length by 40 feet in width, the cement being stored to a depth of about 3 feet 6 inches. This was divided into ten bins, each of which took about 120 tons, to facilitate cooling, testing, etc., the cement being shot as it came from the steamer alongside the temporary pier. On each bin was noted the date of delivery, the date of testing, and the date when ready for use.

A store-shed, 100 feet by 20 feet, was erected, and was furnished with the usual assortment of stores.

An oil-shed was placed at a considerable distance away to avoid danger in case of fire.

A large stone building was utilized for the storage of materials for permanent works.

An engine-painting shed, to take one locomotive.

Blacksmiths' and fitting shops.

Machine and fitting shops.

Boilersmiths' shops.

Brass-moulding department.

Machinery—

- 1 Lubecker excavator, employing twelve men.
- 1 12-ton Wilson excavator.
- 1 10-ton Whitaker bucket-excavator.
- 19 locomotives of various types.
- 21 travelling and derrick cranes.
- 3 Taylor concrete-mixers.
- 3 stone-crushers driven by 10-HP. and 12-HP. engines.
- 24 pumps of different types.
- 15 boilers, vertical and locomotive.
- 5 grabs.
- 2 steam rock-drills.

Portable engines, three 10-HP., two 12-HP., one 20-HP., two 25-HP., and two 30-HP.

Pumps at Main Sump.—One pair 15-inch Cornish rocker-beam pumps steam-driven by spur-gearing; approximate capacity, 800 gallons per minute at 12 revolutions per minute. One 12-inch Wade and Cherry centrifugal pump driven by a 25-HP. engine; approximate capacity, 2,000 gallons per minute. This pump was used for high tides and wet weather.

The temporary water-pipes were $5\frac{1}{2}$ miles in length.

The contractors' railway was about $10\frac{1}{2}$ miles in length.

A temporary jetty on No. 2 bank was constructed, at which frequently two or three steamers were discharging at one time. It was equipped with three 3-ton cranes, and in the busy time these were working day and night.

(*Paper No. 3623.*)

"Design and Working of Gold-Milling Equipment, with special Reference to the Witwatersrand."

By George Alfred Denny, Assoc. M. Inst. C.E.

Although innumerable attempts have been made to supplant the gravity stamp by other machines, constructed either on some similar principle or on quite different lines, it has not only held its own as an ore-pulverizer, but is to-day used almost exclusively in every permanent gold-field. Whether this will continue to be the case in the future is, in the Author's opinion, a matter of doubt.

The competitors of the gravity stamp include the following:—

1. Stamps in which the speed of falling due to gravity is accelerated by springs, cams, steam, compressed air, or some combination of these.
2. Machines which produce impact of the ore upon itself in space.
3. Machines which employ revolving beaters or hammers encased in a suitable wearing shell.
4. Machines which crush by means of rolling surfaces in contact under pressure.
5. Machines which crush by means of one rolling surface in contact with a fixed surface, under centrifugal force.
6. Machines which crush by means of one rolling surface in contact with a fixed surface, under pressure.
7. Machines which employ concentric grinding-disks, with one fixed and one revolving member, either in a vertical or a horizontal plane.
8. Machines which employ spheres of metal or of stone, arranged in concentrically revolving pans, or in enclosed axially-revolving barrels.
9. Machines of the breaker-type, either with jaws or with spindles.
10. Combinations of several of the foregoing in one continuous scheme.

(1) The mill of most modern design included in this section, and one which has run under the supervision of the Author for the past 2 years, is known as the high-speed stamp-mill. The object of the inventors in designing this mill was to obtain a greater number of blows per minute than could be obtained with the ordinary gravity stamp working on the same drop, and at the same time to increase the falling weight of the stamp. It is well known that the limit of speed at which the ordinary gravity stamp can be run is prescribed by the height of the drop, and in general it may be said that with the ordinary arrangement and a drop of 7 inches to 8 inches, 100 blows per minute is the maximum speed which can be obtained. The high-speed stamp was designed to enable the stamps to be run at a greater speed than that mentioned, and to effect this an improved method of lifting the stamps was adopted. Referring to Figs. 1 and 2, Plate 5, a strongly-made crank-shaft, A, driven by means of a belt and having five cranks attached to the same number of cylinders, B, causes the latter to reciprocate between vertical bearings. Each cylinder is cast with an annular chamber, B_1, round the upper portion, the chamber having a port, B_2, at the bottom, opening into the cylinder proper. The cylinder, B, is bored from end to end, and is provided with a gland, B_3, and a stuffing-box, B_4, the gland being a good fit in the stuffing-box, so that it serves as a guide for the piston-rod. The top of the cylinder is fitted with a cover, B_5, which has two lugs to take the gudgeon-pin at the end of the connecting-rod. The water-chamber, B_1, is supplied with water by means of a telescopic pipe, E, fitted to the top of the cylinder at the side of the cover, the inlet of the water-chamber being a few inches from the top of the cylinder. A screw-plug is provided for cleaning-purposes. The bottom side of the cylinder is provided with an outlet for draining off the surplus water; the outlet is fitted with a telescopic pipe leading to a water-channel in the lower stem guide, and has also a screw-plug at the side, by opening which the stamp is brought to rest. The cylinder has four guide-sleeves, B_6, cast on to it, two on each side. These sleeves slide on two circular rods, C, which constitute the guides, the rods being connected at the top and bottom ends to heavy cast-iron cross-beams, F. The whole is carried by a strong cast-iron entablature, G, which is firmly bolted to the top of the king-posts. The bearings for the crank-shaft are formed in the entablature, G, as also is the water-channel, H, from which the fixed pipes of the telescopic connection for the water-supply to the cylinders depend. Two cast-iron side-frames, J, are bolted to the bottom of the entablature, G, being in turn bolted to the cast-iron cross-beams, F, which carry the top and bottom ends

of the cylinder guides, C. The piston, K, works freely in the cylinder; the bottom end of the piston-rod is tapered and driven tightly into a cast-steel adjusting-sleeve, L, being further secured by means of a tapered cotter. The lower end of the adjusting-sleeve, L, is bored out to take the top end of the stamp-stem, M, the stem being held in position by a gib-and-key frictional fastening of the same type as that used in cam-stamp tappets. The stem has a collar, M_1, forged on just below the sleeve, L. This collar prevents the stem from slipping up into the sleeve, and in addition permits of compensating-washers, M_2, being inserted between the collar and the sleeve to make up for the wear of the stamps, thus keeping the total length of the falling parts as nearly as possible the same throughout the life of the stamp, as well as keeping the total weight of the stamp practically constant. The bottom end of the adjusting-sleeve, L, is flanged, and a V-shaped groove, L_1, is turned in the flange to take an endless chain, N, by means of which the stamp is rotated. The top end of the sleeve is also flanged. This top flange, L_2, constitutes the projection by means of which the stamp is hung up, and its bottom side is made of helical form so as to allow for various heights of lift. The hanging-gear, R, is in the form of a bell-crank lever pivoted at the bend. When not in use the crank hangs free of the stamp; on being lifted up, one end of the lever engages with the lower side of the top flange on the adjusting-sleeve, L, and holds the stamp up. The endless chain, N, which passes round the lower flange of the adjusting-sleeve, also passes round a small chain-wheel, P, having an internal friction-pawl which allows the wheel to rotate in one direction only. As the stamp falls, the alteration in the length of the two sides of the chain, due to the angular motion of the stem in relation to the chain-pulley, causes the pulley to rotate. As the stamp rises, this rotatory movement of the pulley tends to take place in the opposite direction, but as the pulley is prevented by the pawl from rotating, the movement is consequently imparted to the stamp. The lower ends of the stem, M, are controlled by guides, S, bolted to frames, F.

The action which takes place during one cycle of the cylinder is as follows:—

The stamp, when resting on the die and having the cylinder at the bottom of its stroke, opens the water-port, admitting water into the cylinder, on the bottom side of the piston. As the cylinder ascends, the port is gradually closed, owing to the piston remaining stationary, the water consequently being forced partly through the gradually closing port into the water-chamber, and partly through the passage into the hollow piston, thus compressing the air in the latter. As

the port closes and the velocity of the cylinder increases, the pressure of the air in the hollow piston gradually increases until it is sufficient to raise the stamp at the speed at which the cylinder is then moving. This pick-up of the stamp is not instantaneous, owing to the cushioning-effect of the air and water. The piston and cylinder then continue to move together, and, as the cylinder-velocity increases until about mid-stroke, the air in the hollow piston, which has a pressure due to the maximum accelerating-force exerted by the cylinder on the piston, re-expands after mid-stroke is passed, and does work on the piston, sending it upwards at a greater speed than that of the cylinder. When the cylinder reaches the top of its stroke it stops momentarily, but the piston, owing to its acquired momentum, continues its upward course for a certain period. Before the piston reaches its highest point, however, the cylinder has commenced its downstroke; consequently the water-port is opened and water is admitted to the bottom of the cylinder. The piston descends freely and independently of the cylinder, and as it descends under the action of gravity its speed gradually increases over that of the cylinder, and the water is driven through the open port back into the water-chamber. The stamp strikes the ore before the cylinder reaches the bottom of its stroke; consequently the cylinder over-runs the piston, thus opening the water-port again, admitting water into the cylinder to make up any deficiency, and the cycle is repeated. As in the first half of the downward stroke the cylinder-velocity is greater than the piston-velocity, it follows that the friction of the walls of the cylinder against the piston, and of the gland and stuffing-box against the piston-rod, gives the stamp an increased momentum over that induced by the action of gravity. This increased momentum is such that, in the lower half of the downward stroke, when the piston is moving at a greater velocity than the cylinder and the friction of the parts mentioned is now retarding the motion of the piston, the final blow of the stamp on the ore is greater than if the stamps fell through the action of gravity alone.

In practice, the work of this stamp has been satisfactory in all respects but one, namely, the cost of maintenance of the pistons. This, however, is a fault which should easily be remedied in future designs.

The mill run under the Author's supervision gave, on an average, about 124 blows per minute, as against an average of 96 to 100 blows per minute by the cam-stamps, the average crushing being between 9·2 tons per stamp per day when the shoes and dies were new, and 8·4 tons per stamp per day as these became worn. No trouble has

been experienced with the cranks or connecting-rod ends. The power required to operate the five stamps was found in practice to be slightly in excess of that needed to operate ten cam-stamps.

The other machines of this class are all well known, and have been described by numerous writers. Perhaps the most important are the heavy steam-stamps built both in England and in America, which are made with steam-cylinders up to 20 inches in diameter, with strokes up to 24 inches. They are arranged as single units and on a screen punched with holes $\frac{3}{16}$ inch in diameter; their capacity is 300 tons to 400 tons per 24 hours, and the power required to drive them is 150 I.HP. to 180 I.HP.

With regard to the remaining classes, it will be sufficient to indicate the type of machine included in each class, as the types are well known and particulars of them are to be found in standard works:—

Class.	Typical Machine or Combination.
2.	Sturtevant Cyclone Crusher.
3.	"Clero" Pulverizer.
4.	Krom Rolls.
5.	Huntingdon Mill.
6.	Chilian Mill.
7.	Grinding-Pans, Buhr Mills.
8.	Ball- and Grit-Mills and Berdan Pans.
9.	Blake and Gates Breakers.
10.	Breakers, Rolls, Stamps, Pans, and Grit-Mills.

It will be seen that the mill-man has a variety of types and combinations from which to choose, but it may be said of the majority of them that they are used practically exclusively for special conditions, and do not, except in combination, fulfil the requirements of the most general practice. A combination which the Author believes might eventually supersede the stamp-mill arrangement will be described later.

The large-capacity steam-stamp, which is employed to advantage in the copper regions of America, has not been adopted for general work.

The Huntingdon Mill has been advantageously used in out-of-the-way mining-camps, and generally in the earlier stages of a district's development; it is particularly suited to ores of a clayey nature.

The Chilian Mill is used exclusively for special work, generally on thin veins of rich ore. This type of machine, designed to give a large output, is one which, in the Author's opinion, will be more extensively employed in the future.

Grinding-pans are essentially stage-machines; they have been well tried, and their capabilities as fine grinders and amalgamators are

well known. They form an important link in the Author's proposed scheme of reduction and treatment.

Machines of the cyclone, pulverizer, revolving beater, and roll classes have all their adherents, but cannot be said to have been extensively adopted by mining engineers on the world's permanent gold-fields.

It will be seen that the one form of pulverizer which has found favour in all parts of the world, and amongst mill-men operating on all classes of ore, is the gravity stamp. This Paper will therefore be limited to a consideration of the design of the gravity stamp-mill, and of the objections to it which may be raised; at the same time features of plant, and especially of that in use on the Witwatersrand and erected to the Author's design, will be discussed.

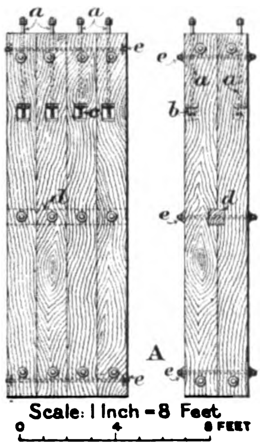
A cross-section and a sectional elevation of a modern mill erected to the Author's design are shown in Figs. 3, Plate 5. The mill contains the stamps, grouped together in batteries of five, placed in two rows, back to back. The ore-bins, F, for feeding the mortar-boxes, G, run down the centre of the building between the two rows of stamps. This arrangement necessitates the use of only one ore-conveyor, X, and tripper, X_1, to feed the two bins, F, from the crusher-house. The cam-shafts, K, are belt-driven from one line of shafting, P, on each side of the house. Every group of five stamps has a separate drive and belt-tightener, N. A travelling crawl, W, is arranged directly over each row of stamps to enable any stem, J, to be lifted out of position. Another crawl, V, is also fitted over the tables for the handling of the shoes and dies. The mortar-boxes, G, are set on heavy wood-piles, A, bolted together and resting on concrete foundations. A gallery is provided in front and behind the cam-shafts, and a feeder-platform behind the mortar-boxes. Wooden launders, T, for conveying the pulp away to the tailings-elevator, run down each side of the house, receiving the overflow from the amalgam-traps, U; and QQ are the mill water-service mains.

Mill Foundations.—The foundations of a stamp-mill must in all cases receive most careful attention, although obviously the nature of the ground on the mill-site must ultimately determine the precise scheme to be adopted. In loose soil, such as is frequently encountered on the Rand to a depth of 50 feet to 60 feet, not only is it necessary to observe every ordinary precaution, but the load must be so distributed as to impose not more than 1·5 ton of superincumbent weight per square foot of foundation, on account of the tendency of the soil to movement if in a wetted condition. The portions of a mill which require foundations, apart from the building, are the "pile" or "mortar-" blocks and the mud-sills. If, as sometimes

happens, the hard quartzites forming the sediments characteristic of these fields are found practically on the surface, the question of foundations is much simplified.

"*Pile-*" *or* "*Mortar-*" *Block.*—The pile-block, strictly speaking, must always consist of timber, whilst the mortar-block may consist of either concrete or cast-iron, or some combination of these, with or without planking as an accessory. The form of pile-block most generally adopted consists of eight pitch-pine logs, A, *Figs.* 4, 15 inches by 16 inches, and of varying length. Four of the logs in each block are carefully straightened and squared on two sides, and the other four on three sides, and in the centre of each block is a longitudinal key of pitch-pine, *d*, 8 inches square, the object of which is to check any possible movement amongst the several members of the block. The whole block is solidly bolted together with sixteen $1\frac{1}{4}$-inch bolts, *e*. Holes for the mortar-box holding-down bolts, *a*, are bored in the piles, as indicated by the dotted lines, and the almost universal practice is to cut hand-holes, *c*, in the front and back of the block, for placing cotters, *b*, in the holding-down bolts. This plan is satisfactory if the holding-down bolts receive careful attention and are always kept tight; but in most mills they are not easily accessible and are consequently neglected, the result being that, owing to the small surface presented by the cotter-pin washers, and the great vibration of the mill, the end grain of the wood becomes bruised, and finally the hand-holes lose all shape, and it becomes impossible to keep the holding-down bolts tight. Instead of cutting hand-holes, as shown in *Figs.* 4, the Author prefers to cut channels out of the block and insert stiff angle-bars, as shown in *Figs.* 5. This is found to be a distinct advantage in practice. In *Figs.* 5, a_1 are the holding-down bolts, b_1 the cotters, c_1 the channel, f_1 the angle-bar in the channel, d_1 the key, e_1 the binding-bolts, and A_1 the complete block.

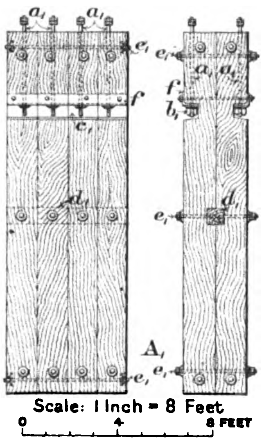
Figs. 4.



Another method of placing holding-down bolts is to run embedded bolts of large diameter longitudinally in the blocks, and to attach to these the eye-bolts necessary for holding down the mortar-boxes. This method has the advantage over the ordinary method first enumerated that the pile-blocks cannot be affected by carelessness

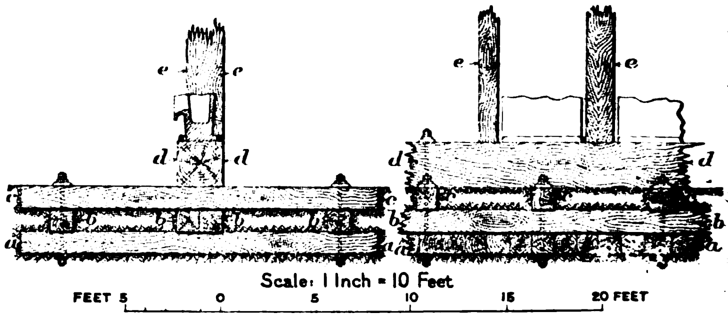
on the part of the mill-men with regard to the holding-down bolts, but it has the disadvantage of inaccessibility should one of the holding-down bolts become broken. As far as the Witwatersrand is concerned, however, the day of wooden pile-blocks has in all probability almost passed, not because the blocks do not present an effective medium, but because of the rapid decay which many of them have undergone, and the great cost involved in renewals and in delays.

Figs. 5.



In very spongy ground, a pile-block of special construction, shown in ***Figs.* 6**, is employed. This differs somewhat from the usual form, inasmuch as a horizontal framework of timber is made to form the foundation. Heavy bottom-timbers, *a*, 15 inches by 15 inches, and up to 20 feet in length, are first laid at right-angles to the cam-shaft, and placed side by side throughout the length of the mill. Lying on these are the mud-sills, *b*, parallel to the line-shaft, two of them under the boxes, close together, and the others spaced evenly on the projecting length on either side of the centre On these are placed cross-sills, *c*, of similar dimensions, laid paralle to the lowest timbers, *a*. All sets are strongly bolted together an

Figs. 6.

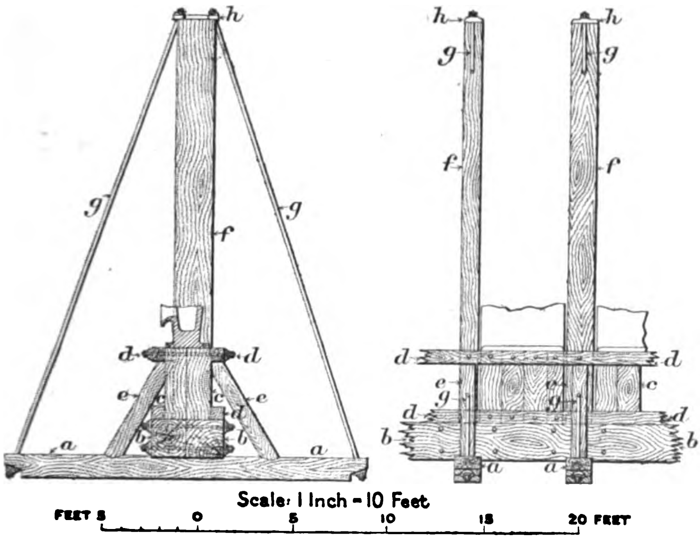


ballasted with any suitable material, great care being taken t ensure good drainage. On the frame so prepared is laid a horizont block of timber, *d*, 30 inches by 30 inches, upon which the morta box rests, the latter being bolted down to the under-frame. Th

king-posts, *e*, are mortised into the mortar-block at the proper intervals.

Another form of block, shown in *Figs. 7*, consists of bottom-timbers, *a*, 15 inches square and up to 20 feet in length, placed at right-angles to the cam-shaft and spaced according to the king-posts, *f*. Lying on these, and parallel to the cam-shaft, are laid very heavy timbers, *b*, bolted together, and upon these are placed piles, *c*, on end, as in the form previously described. These vertical blocks, *c*, are stayed by struts, *e*, to the underlying cross-timbers, *a*, and are bound together by two sets of continuous stringers, *d*. The

Figs. 7.



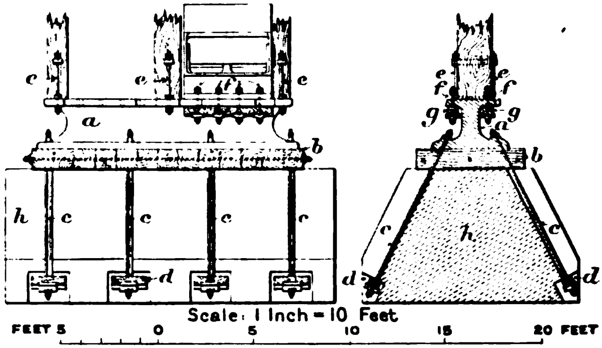
king-posts, *f*, are mortised into the horizontal pile-blocks, *d*, and are held in position by two strong straining-bolts, *g*, passing from a cast-iron bonnet, *h*, on top of the king-posts, *f*, to the ends of the bottom cross-timbers, *a*, as shown in *Figs. 7*.

These forms would naturally be adopted only in localities in which timber is plentiful and cheap, as a more lasting structure could be secured by excavating and concreting a wide bed, upon which the ordinary construction could then be raised.

Mortar-Blocks.—The mortar-blocks proper are constructed of materials other than timber, and generally of concrete and cast-iron anvil-blocks, or of some combination of these. Mill-designers have been loth to adopt the more rigid forms of mortar-blocks, as

represented by concrete and iron, on account of their want of resilience when compared with timber, and the supposed deleterious effect of their rigidity upon the component parts of the mill. Experience, however, has shown these fears to be groundless, and has further demonstrated that the use of the more rigid blocks has tended to increase the stamping capacity. A combination of the cast-iron anvil-blocks and concrete foundation-block, designed by Mr. A. M. Robeson and used by him in mill-construction, is shown in *Figs. 8.* The underlying concrete block, *h*, is made up in the following manner:—A wooden boxing for the concrete block is set up in the position which the block is to occupy. A concrete mixer is employed, erected on a staging about 20 feet above ground-level. Concrete composed of four parts of stone, two parts of sand, and one part of cement is passed through the mixer, dropped from it into

Figs. 8.



trucks, and tipped from a height into the boxing. A block to take two mortar-boxes, or ten stamps, is put down in one operation, in order to make a solid block free from joints. The total quantity of concrete in the block measures about 62 cubic yards.

The Anvil-Block.—The anvil-block, *a*, in this construction rests on the timber mat, *b*. Eight bolts, *c*, lying in slots, hold the block, together with the mat, down to the underlying concrete block. The holding-down bolts have wooden blocks, *d*, fixed to their lower ends. The king-post and mortar-box are bolted on to the anvil-blocks by vertical holding-down bolts, *e* and *f*. The bolts, *f*, for the mortar-box have wooden blocks, *g*, under the upper flange of the anvil-blocks.

Battery-Framing.—The battery-frames are of various forms, and are either of wood or steel, the two prominent types being the "A-" type and the "knee-" type. A frame of the knee-type, recently constructed under the Author's supervision, is shown in Figs. 3,

Plate 5. A feature of this mill is that the bottom beams, *a*, are carried through from the back bin-posts, *b*, to the king-posts, D, the knee-beams being carried on a longitudinal cap, *c*, which is again carried by the lower front posts, *d*. This form of framing renders it necessary to erect almost every beam separately, which involves some expense, but the stiffness of the subsequent structure well warrants the enhanced cost. If the front and back parts of the bin had each risen independently from the strake-sills, it is clear that the frames could be built on the ground and brought into position in sequence, but the stiffness secured by the former method would be wanting. The various parts of the mill-framing are shown in Figs. 3, Plate 5. It will be seen that the mud-sills, B, consist of timbers, 15 inches by 15 inches, placed on concrete blocks running longitudinally the whole length of the mill. Lying across these are the strake-sills, C; of these the larger logs, required for the centre king-post in each mill, are 18 inches by 18 inches, and the others are 12 inches by 18 inches. In constructing the frame the mud-sills are placed in position, and are bolted down to the concrete blocks before the mortar-blocks are dropped into the pile-pit, the length of the splices on the mud-sills being made about three times the thickness of the timber employed. As soon as the mortar-boxes have been dropped into the pits, the strake-sills are placed in position and bolted down to the mud-sills, after which they are carefully levelled in preparation for the superstructure. The king-posts, D, which carry the cam-shafts, K, and the stamp guide-stringers, E, and guides, E_1, are then placed in position. In the battery of ten stamp-units, the centre king-post is heavier than the outside posts, since it carries a long bearing in which the ends of the two separate five-stamp cam-shafts rest. The centre king-post is usually 24 inches by 18 inches, and the outside posts 24 inches by 12 inches. The ratio of tenon to sectional area of the post is 0·12 for the 24-inch by 18-inch timbers and 0·18 for the 24-inch by 24-inch timbers. After the erection of the king-posts the mortar-block binders, A_1, are fitted. These consist of 8-inch by 8-inch timbers, one carried flush with the top of the mortar-block and the other lying on the strake-sill against the mortar-block. The space between the king-posts and the mortar-blocks having been carefully filled, the binders bolt the king-posts and the mortar-blocks securely together. This work needs to be carefully done and the joint to be perfectly made, so that when the mill is at work and water-leakage gets on to the wood-work, the latter will swell and become practically solid and therefore sand-proof. The bin-framing having been erected, the ore-bin, F, is lagged with 9-inch by 3-inch deals overlaid half-way up from the

bottom with 9-inch by 2-inch timbers on the bin-front and throughout the bin-bottom. This lining is protected by ½-inch steel plating. The inclination of the bin is usually about 40° to the horizontal. The capacity of the bin should be at least 40 hours' supply for the mill, in order to provide for Saturday afternoon and Sunday.

Mortar-Boxes.—The mortar-box shown in Figs. 9, Plate 5, and designed some years ago by the Author, may be used for general description. It is made of cast-iron with a false steel bottom, *a*, and a removable steel wearing-plate, *b*, at the sides, front, and back. The ore is fed in at the back through a hopper, *c*, and, falling on to the dies on the bottom of the box, is crushed by the action of the stamps. In front of the box, and along its whole width, is an opening, *d*, before which a mesh-screen is fixed. The continuous dropping of the stamps in presence of water produces a pulp, which when fine enough passes through the screen on to amalgamating-tables. The weight of the mortar-box shown in Figs. 9, Plate 5, is about 8,260 lbs., the overall height being 5 feet 4 inches and the dimensions of the base 4 feet 10 inches by 2 feet 4 inches. The thickness of the metal in the bottom of the box is 10½ inches, and each box is fitted with a false bottom, 2½ inches in thickness, so arranged as to be easily removable when worn. The box is held in position by eight cotter-bolts fixed in the mortar-piles. The screen-opening is 4 feet 4 inches in length by 1 foot 7 inches in height. In this opening is placed a pitch-pine frame, which is dropped into a prepared recess in the front part of the box and firmly held in position by two gibs, one at either side of the opening. The gibs are 1 foot 10 inches in length by 1¼ inch in breadth, and taper from 2½ inches to 1¼ inch. The screening, which varies in mesh on these fields between 400 holes and 1,000 holes per square inch, is tacked on to the frame in such a way as to be easily detached when worn or broken.

The great variety in the existing patterns of mortar-boxes is evidence of the wide differences of opinion amongst mill-men as to the special features to be incorporated in their design. The mortar-box would appear to be an apparatus the functions of which are unvarying, and therefore departures from a fixed approved type might reasonably be regarded as more or less whimsical. In point of fact, however, mortar-box design can only be intelligently carried out with a full knowledge of the particular ore which is the object of treatment.

The dies, shown in Figs. 10, Plate 5, and in their position in the mortar-box in Figs. 3, Plate 5, are made of forged steel. The shoes, which are shown in Fig. 11, Plate 5, and in position for work in

Figs. 3, Plate 5, are 12 inches in length and 8¾ inches in diameter. It is desirable to have shoes even longer than 12 inches, say 14 or 15 inches in length, as the loss by scrapping when the shoe is worn out is obviously less with the longer shoe. The shoes are forged with a shank for attachment to the head. The head is shown in Figs. 12, Plate 5, and in position for work in Figs. 3, Plate 5. These are of cast steel, with a finished tapered socket at one end to take the stem, and a rough tapered socket at the other end to receive the shank of the shoe. A slot, *s*, is provided at the bottom of each socket for the purpose of introducing tools for the removal of the stem or shoe. The heads are usually 1 foot 6 inches to 2 feet in length and 9 inches in diameter, and weigh 275 lbs. to 377 lbs. each. The longer and heavier heads in a mill should be so arranged that the partially-worn shoes from other parts of the mill can be fixed to them, and new shoes fixed to the shorter heads. The stems are made of faggoted iron or mild steel. They are 16 feet in length, weigh 565 lbs. each, and are tapered at both ends to receive the head. It has been found in practice that a good iron, such as Lowmoor or Farnley iron, makes the best stem-ends, for the reason that when a stem breaks close to the head, as it usually does, a new end about 3 feet in length is readily welded on to the body of mild steel. A mild steel body is generally preferred by mill-men, as it wears better in the guide-blocks. It is found necessary in practice to anneal the stems periodically in order to restore the molecular structure, as the constant jar and vibration during work tend to crystallize the steel and render it short. The tappets are shown in Figs. 13 and 14, Plate 5, and in position for work in Figs. 3, Plate 5. They are of cast steel, 14 inches in length and 9 inches in diameter, and weigh 148 lbs. Numerous methods of fixing the tappets to the stems have been tried, but the simplest, and perhaps the best, is the one at present almost universally in use, in which a gib, *g*, about 9½ inches in length, is held hard against the stem by three 1-inch square keys, *k*, having a good "draw." The tappet, which is reversible, has a recess, *r*, at each end to ensure even wear of the cam and tappet faces.

Guide-Blocks.—Innumerable devices for guiding the stamp-stems have been introduced and used with more or less success. The principal object to be aimed at in the design of a guide-block is to secure true alignment combined with the minimum of friction. It is obvious that if a stamp-stem is out of the vertical in any direction, great friction is set up, causing the stamp to hang in the guides, preventing rotation—which is essential to regular wear of the shoes, dies, cams, tappets, etc.—decreasing the effectiveness of

the blow, and causing the shoe to strike against the sides of the box. Notwithstanding the great number of appliances, both in wood and metal, which have been devised to meet the special requirements of a stamp-guide, the great majority of mill-men favour the old-fashioned guide-block illustrated in Figs. 15, Plate 5. These are made of various woods, notably English beech, African stinkwood and lead-wood, and some varieties of Australian hardwood. Of these the Author's preference is for English beech, as it has a good life without unduly wearing the stamp-stems. The African and Australian hardwoods make excellent guides, but they cause rapid wear of the stems, and consequently also give rise to unfavourable conditions for the lift, and to excessive vibration. The guide-blocks, *a*, are made in halves, bolted together with bolts, *b*. These same bolts also secure the blocks to the girt, *c*, which is bolted on to the back of the king-posts of the battery. One half of the guide-block is permanently fixed to the girt by the square part on the bolts, *b*; the other half can be taken off for the removal of the stems. Wooden liners, *d*, are clamped in between the two halves of the guides.

Sectional Guides.—Many forms of sectional guides have been designed, but few of them have proved successful in practice, chiefly owing to the number of loose parts of which they are composed, the difficulty of keeping these properly adjusted, and the consequent high cost of maintenance. One of the most successful is illustrated in Figs. 16, Plate 5. Each stem, *a*, moves in a separate pair of hard-wood guide-blocks, *b*, adjusted by two hardwood wedges, *c*, fitted in suitable lugs in the cast-iron or steel guide-frame, *d*, which is attached to the usual guide-stringer, *e*, by countersunk bolts, *f*.

The advantages of this form of sectional guide are:—

(1) Any stamp can be "hung up" for repair or adjustment of its guides without interfering with the others; and as each pair of guide-blocks can be kept wedged "hard up," lost motion is reduced to a minimum.

(2) The vibration of the mill tends only to tighten the adjusting-wedges.

(3) The guide-blocks can be made with the grain of the wood parallel to the direction of movement of the stem, presenting a smoother and more lasting surface than in the ordinary form.

Jack-Shaft and Finger.—The jack-shaft and finger for "hanging up" the stamps clear of the cams are shown in Figs. 17, Plate 5. The jack-shaft, *a*, is supported in cast-iron brackets, without caps, bolted to the king-posts, *b*. Upon the jack-shaft the fingers are mounted centrally with the stamp-stems. Each finger consists of a timber strut, *c*, shouldered into a cast-iron saddle-piece, *d*, and is pro-

vided with a handle, *e*, and a protecting-cap, *f*, as shown. The saddle-pieces and brackets permit of the ready removal of both fingers and jack-shaft for repair or renewals. The stamp is "hung up" by inserting a cam-stick (an implement made of a number of strips of leather fastened to a wooden handle) between the cam and the tappet, thus giving the stamp about an inch extra lift. As the stamp reaches its highest point the finger is pushed into the position shown by the dotted lines. To drop the stamp, the lifting-operation is repeated and the finger is withdrawn.

Cam-Shafts.—A form of cam-shaft now largely in vogue on these fields is shown in Fig. 18, Plate 5. It is an adaptation of the Blanton form of cam-shaft (Fig. 19, Plate 5), but whereas in the Blanton system a tightening-wedge is inserted between the cam and the cam-shaft, in the system illustrated in Fig. 18, Plate 5, the studded wedge is replaced by a swelling on the shaft.

Blanton Cam-Shaft.—The Blanton cam-shaft (Fig. 19, Plate 5) is made of mild steel or faggoted iron, and has holes drilled in it at appropriate intervals to give the required drop, the cams being made all alike. The cam-shaft pulley is usually keyed to the shaft as shown, but sometimes it is fixed with a Blanton taper-bushing like the cams. The "New" Blanton cam-shaft (Figs. 20, Plate 5) has its circumference divided into ten taper-faces corresponding to the ordinary taper-bushings, and the cam (Fig. 21, Plate 5) is made with ten slots accurately divided to fit these faces. It is evident that this construction gives great flexibility in the arrangement of the cams on the shaft, whether for a five-stamp or a ten-stamp unit, and for any drop. The stress on the boss is much more evenly distributed than with the older single-taper bushings. The ends of the shaft are, of course, turned, to form the journals and to receive the collars and cam-shaft pulleys. The ordinary Blanton taper-bushing is shown for the attachment of the pulley.

In the earlier types of cam-shafts, two key-seats were cut along almost the whole length of the shaft, and the positions of the cam on the shaft's circumference were fixed by so disposing the key-ways in the hub of the cam as to give the proper circumferential distribution. This type of cam-shaft has, however, become a thing of the past. It presents such practical difficulties in working as the following:—

(1) The vibration of the mill renders it almost impossible to keep the keys tight, and hence the cams are liable to move into contact with the stem, causing great friction and wear; the constant driving of keys, also, soon destroys the key-seat.

(2) In the event of a cam breaking, the time and labour spent in removing others before the broken cam can be withdrawn involves

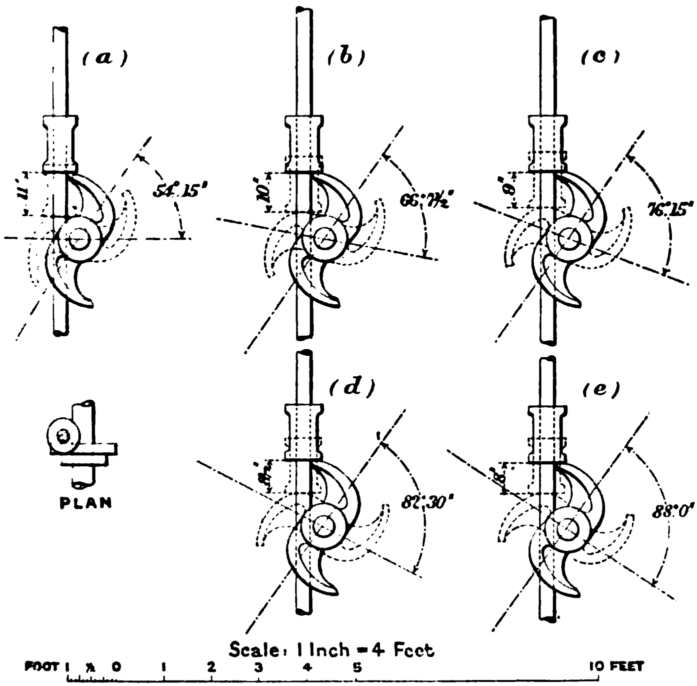
considerable expense, notwithstanding that in all well-regulated mills there is kept in reserve a complete spare cam-shaft to every fifty stamps. With the Blanton and similar types of cam-shafts, owing to the wedge-like construction of the keying-device, the cams tend to become more tightly wedged in working, and when it is desired to remove them they are easily loosened by a few blows on the toe of the cam. A set of five cams of this pattern can be fixed in 10 minutes.

The cam-shaft illustrated in Fig. 18, Plate 5, is 7 feet 10½ inches in length and 6 inches in diameter, turned down at the ends to 5½ inches to run in sunk bearings, which are 12 inches in length in the centre king-post and 9 inches in length in the outer posts. The bearings for the cam-shafts are usually made in a box-casting lined with Babbitt-metal or some similar alloy. There are, however, objections to the use of these alloys on account of their tendency to crumble under the continuous shocks to which the cam-shaft is subjected, and to fall into the mortar-box and eventually form base amalgam, which is not only deceptive in itself, but causes losses in refining. The form of bearing now adopted by the Author is one of plain cast-iron (Figs. 22, Plate 5), turned to the diameter of the crank-shaft journals, and giving ample bearing-surface. This form of bearing, when lubricated with a mixture of graphite and grease, is most satisfactory. It causes no loss of time from re-metalling bearings and does not interfere with the process of amalgamation. The cam-shaft pulleys, K_2 (Figs. 26, Plate 5), are built of well-seasoned clear pine timbers, *d*, 1¼ inch in thickness, securely bolted with ¾-inch bolts, *e*, to a cast-iron centre, *a*. The plate, *b*, is secured to the boss, *a*, by keys, *c*. Great care must be taken in building the pulleys to see that each layer of timber is well bedded, glued and firmly screwed to the others. An iron pulley is unsuitable for the work owing to the shocks carried through from the cams.

Cams.—The function of the cams is to lift the complete stamp to a given height and release it for the crushing blow. The design of the cam has undergone no radical changes for many years past, although certain details relating to the material, the length of the cam, and the method of affixing it to the cam-shaft, have been modified or altered. The theory of the cam-curve has been so frequently and fully explained that it is unnecessary to repeat it here. The cam in use on the mines with which the Author is connected is shown in Figs. 23, Plate 5. The shaft is enlarged at the places where the cams are to be fixed, the key-seats being formed by eccentric faces, the relative position of which permanently determines the order of drop. Phosphor-bronze keys (Figs. 23, Plate 5), curved on the inner face to fit the eccentric-seat, are used for fastenings.

The following are the leading dimensions of the cam:—Radius of toe, 17 inches; bore, 6 inches; diameter of boss, 11 inches; length of boss, 5½ inches; depth of arm at boss, 9 inches; width of arm on face, 2½ inches; thickness of web, 1¼ inch. The Blanton cam (Fig. 24, Plate 5), which is in universal use and of the same general design as the cam illustrated in Figs. 23, Plate 5, is affixed to the cam-shaft by means of curved taper-wedges (Figs. 25, Plate 5) studded to the shaft, providing a friction-hold against the direction of rotation,

Figs. 27.



between the cam-shaft and the cam, and was designed to replace the old keyed cam. The cam is bored and machined to fit a taper-bushing, shown in Figs. 25, Plate 5, which in turn fits on the shaft and is retained in its proper position by two pins fitting into holes in the shaft.

The relative positions of the tappet and cam at the point of release, and the angles, for drops varying between 11 inches and 8 inches, which the cam describes from the point of release by one arm to the point of "pick-up" by the other, are shown in *Figs. 27*. Owing to

the velocity with which the stamp is lifted, the actual lift exceeds the nominal lift by an amount called the momentum-lift, which varies as the square of the velocity. The determination of this amount has been dealt with by other Authors. Referring to the case of the 8-inch drop, the time required for the stamp to drop through this height, neglecting friction, is 0·205 second. To this is added 0·102 second to allow for the momentum-lift, for friction and for a period of rest between successive drops, the latter been found necessary in practice in order to obtain the full effect of the blow. This gives a total time from release to "pick-up" of 0·307 second. The speed of revolution must be such that the angle shown, viz., 88 degrees, shall not be described by the cam in less than 0·307 second; otherwise "camming" will occur.

$$\text{An angle of 88 degrees} = \frac{88 \times 2\pi}{360} = 1 \cdot 535 \text{ radian,}$$

$$\text{and} \quad \frac{1 \cdot 535 \text{ radian}}{0 \cdot 307 \text{ second}} = 5 \cdot 00 \text{ radians per second.}$$

$$= \frac{5 \times 60}{2\pi} \text{ revolutions per minute}$$

$$= 47 \cdot 75 \text{ revolutions per minute}$$

$$= 95 \cdot 50 \text{ drops per minute, since there are two drops to every revolution.}$$

The nominal drop is that from the point of release to the bare die, and this amount is increased by the momentum-lift, which at 100 drops per minute is about $\frac{3}{16}$ inch. With a nominal drop of 8 inches the total drop to the bare die at 100 drops per minute is therefore, say, $8\frac{3}{16}$ inches. The actual drop is the difference between this amount and the thickness of the ore on the die, and is usually about 7 inches. It is necessary, however, in calculating the required speed, to allow for the full drop in order to provide for any temporary cessation of the ore-feed. The practicable limits of stamp-running are 104 blows per minute with a 7-inch drop, and 98 blows per minute with an $8\frac{1}{2}$-inch drop. It is usual when starting with new shoes to adopt the former combination; as the shoes wear, the drop increases, and the number of blows per minute decreases.

Belt-Tightener.—The belt-tightener, shown at N in Figs. 3, Plate 5, consists of pulleys fitted in a double arm suspended from the joists of the cam-shaft floor. The double arm is drawn towards the cam-shaft belt by means of a rope wound round a drum, on one end of which are cast teeth to take a ratchet-pawl. The drum is turned by means of a hand-wheel, and when the belt is sufficiently tight the pawl

is engaged with one of the teeth. The drum is carried by a bracket, which is bolted to the side of the king-posts. The belt-tighteners are rendered necessary by the short drive available with the counter-shaft in the position indicated in Figs. 3, Plate 5. They can be eliminated by carrying the belts in a position which gives a longer drive.

Mill-Shafting.—In a new 120-stamp mill, arranged as shown in Figs. 3, Plate 5, the shafting is 119 feet 6 inches in length, made up of the following lengths and diameters, the greatest diameter being, of course, at the engine end:—

Length.	Diameter.
31 feet	7 inches.
18 feet 9 inches	6½ „
18 feet 9 „	6 „
18 feet 9 „	5½ „
18 feet 9 „	5 „
13 feet 6 „	4½ „

The driving-pulleys on the line-shaft are 30 inches in diameter and 12 inches in width on the face, and are substantially built of cast iron. The shaft is carried on fifteen bearings, two on piers at the driving-end, one on each strake-sill and one on the trestle carrying the cam-floor, at the end furthest removed from the engine.

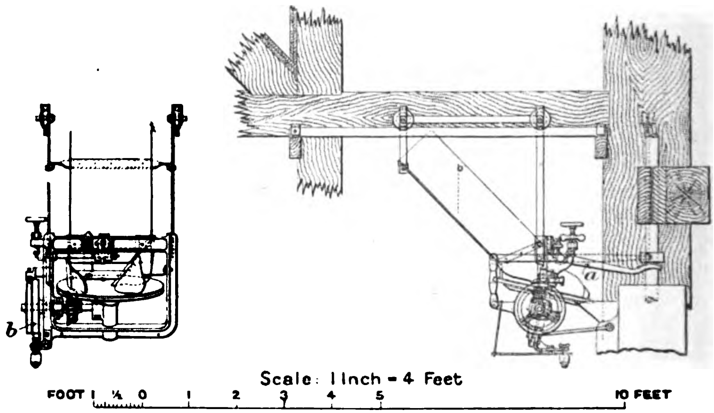
Amalgamating Copper Tables.—These are shown in Figs. 28, Plate 5. They are constructed of red wood and are supported on wooden trestles, *a*, with wedges, *b*. The tables are covered with copper plates, S, flanged at the sides and at the top. A vertical wooden down-pipe, *c*, is attached to the end of each table, leading to a cast-iron mercury trap, U, having a capacity of about 0·85 cubic foot, which is designed to catch any mercury or amalgam which may have escaped from the amalgamated plates. It is fitted with a suitable plug for drawing off mercury and amalgam. In recent practice in Western Australia two amalgamating-tables are provided for each five stamps, in order to minimize delays due to dressing and scraping plates. At the head of the plate a catch-box is arranged which receives the effluent from the mortar-box. This catch-box is provided with an outlet for each plate. When dressing or scraping either of the half tables, the whole of the pulp is turned on to the other, thus avoiding the necessity of hanging up stamps. The saving of time on some mines would amount to 15 hours per month, equivalent on a 100-stamp mill to an increase of 300 tons milled per month.

Shaking Amalgamating-Tables.—These are shown in Figs. 29, Plate 5. The pulp from the tube-mill flows directly over the shaking-table H through the launder, *a*. The table is lined with amalga-

mated copper plates, and the pulp flows into the catch-box, *b*, situated at the lower end, passing thence for further treatment. The longitudinal rocking-motion is given to the table by means of three connecting-rods, *c*, driven by eccentrics on the shaft, *d*, the other ends of these rods being bolted to brackets, *e*, on the underside of the table framework. Two flywheels, *f*, are keyed on to the shaft, *d*. The vertical flat steel springs, *g*, support the table and have rubber washers at the top and bottom. Brackets, *h*, are provided to support the table in case of breakdown of the springs. The shaft, *d*, is belt-driven through pulleys, *j* and *k*; and the countershaft, *l*, with fast-and-loose pulleys, *m*, is driven off the countershaft, *n*, and pulley, *p*. The necessary incline of the table is regulated by the hand-wheel and screw, *q*.

"*Challenge*" *Ore-Feeder.*—The suspended "Challenge" ore-feeder, *Figs. 30*, is an apparatus for automatically feeding ore to each set

Figs. 30.

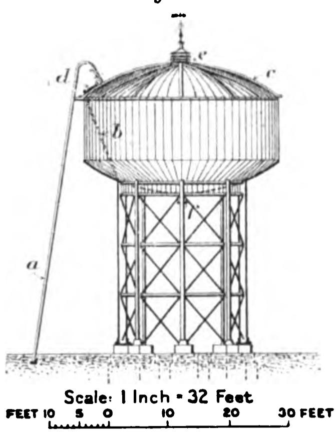


of five stamps. The drive (*a* and *b*) requires constant attention and adjustment and many repairs and renewals, and is not considered satisfactory. Various improvements have been suggested and adopted. That shown in Figs. 31, Plate 5, devised by a mill-manager working under the Author, is a very satisfactory contrivance. This friction-drive consists of a disk, *a*, keyed to the shaft, *b*. Running loose on this shaft is the double-bossed lever, *c*, to the end of which are attached the levers in connection with one of the stems of the battery. An upward movement of the lever, *c*, causes the steel friction-block, *d*, to become wedged between the tightening-block, *e*, and the inside rim of the disk, *a*. Consequently the disk will rotate.

The block, *e*, hangs loose on the adjustable pin, *f*, and the adjustment for wear is made by moving this pin along the slot, *g*, in the lever, *c*. The cost of upkeep of other parts of the feeder is very low, the chief item being the hopper, which costs £3 to make and lasts 18 to 20 months. When the revolving table, *a*, becomes worn, a wearing-piece of ½-inch steel plate is riveted to it; this has a life of approximately 2 years.

Mill Water-Service.—The mill water-service is usually obtained either from a high-level earth reservoir, or from elevated tanks—more often from the former. The mill-water, after passing through the tailings- and slimes-plants and being more or less clarified, is allowed to gravitate to the main storage-reservoir, from which it is pumped again to the steady-head reservoir or tanks, whence it begins another round. In the system arranged by the Author, the bulk of the water is cleared in one operation, in large conical separators, and is returned direct to the mill-mains, thus avoiding loss of water and cost of pumping. The mill service-tank adopted by the Author is illustrated in *Fig. 32.* It will be noticed that the bottom of the tank is dished, thus allowing a considerable overhang beyond the staging. The special feature of the construction of this tank is that the staging is very considerably economized, the saving in weight of staging and girders as compared with that required by the ordinary flat-bottom tank being approximately 6 tons. The tank is carried, as shown, on a built-up circular girder-ring, and as it obviously requires no bottom supporting-girders, the cost of these is saved. The capacity of the tank is 66,000 gallons. A ladder, *a*, leads to the outside of the tank, and another ladder, *b*, gives access to the interior. The tank has a dome-shaped steel cover, *c*, with angle-bar ribs and a man-hole, *d*, for access to the interior, and is surmounted with a ventilator, *e*. The discharge-pipe, *f*, is at the bottom, in the centre of the tank. In the Author's plan of returning the separated water directly to the mill-mains, the only water drawn from these tanks is that required to compensate for the loss of water in milling. This loss, it is expected, will be cut down to about 120 gallons per ton of ore milled, so that the storage in each

Fig. 32.



tank of this size is equivalent to the loss for 24 hours on a mill of 100 stamps, crushing 500 tons per day.

The average total quantity of water required to be fed through mills of modern design is approximately 10 tons of water per ton of ore crushed, and since a heavy-pattern mill, having a falling weight of, say, 1,250 lbs., will crush 5 tons per day, through a 600-mesh screen, the water required is 35 to 40 gallons per minute for every 5-stamp mortar-box.

The losses of water in milling are attributable to (1) moisture in residues, which amounts on an average to 10 per cent. of the weight in sands and 50 per cent. in slimes; (2) leakage and soakage; and (3) evaporation. In districts in which water is scarce, every effort must be made to separate the water from any matter in suspension and clarify it for further use. On the Witwatersrand the usual method of clarifying the mill-water is to run it, together with the slimes held in suspension, into dams or impounding-areas formed of earthwork, of varying dimensions up to 1,000 feet square. The water and slimes are delivered at one side of the dam, and travel across the dam to the point of outlet, the time absorbed in the passage being generally sufficient to effect a fair settlement of the suspended slimes. The clear water usually runs from the slimes-dam to a neighbouring storage-reservoir, from which the main mill-supply is pumped. Losses both from leakage and soakage are naturally inseparable from this arrangement. The greatest losses, however, are due to evaporation. The general scheme on these fields is to have a main storage-reservoir placed in some suitable position for impounding water in the rainy season. These reservoirs have surface-areas, in general, out of all proportion to their depths, so that the effect of evaporation is felt in the highest degree. From the storage-reservoirs water is pumped to a high-level reservoir for mill-supply purposes, and here again a large surface of water is exposed. The slimes-dams previously referred to offer a third evaporative surface, so that in all there are three areas of shallow water giving off vapour to the atmosphere. The average evaporation on the Witwatersrand is rather more than 60 inches per annum, and it can therefore be readily realized to what an extent the slender water-resources of many mines suffer from this cause. The average rainfall is about 30 inches per annum, but probably the run-off does not exceed 5 per cent. The loss of water in milling-operations ranges between 200 and 800 gallons per ton of ore crushed, with a probable mean loss of 500 gallons for every ton of ore milled. Being impressed with the magnitude of these losses, and observing that there was not only loss of water, but loss of

power in constantly circulating water to and from the storage-reservoir, the Author was led to design the tank shown in Figs. 33, Plate 5. The object of providing this tank was to secure in one operation a thickening of the slimes-pulp and a separation of clarified water for immediate return to the mill-mains. The pulp entering this tank consists of the whole of the water passing through the mill, less the quantity retained in the settled sands, carrying in suspension the slimes created in the stamping-process. The pulp entering the tank consists of 3 per cent. of solids, in the form of slimes, and 97 per cent. of water. This pulp is delivered into a cylinder suspended centrally in the tank and immersed in it to a depth of about 6 feet. The action in the tank is such that a more or less perfect separation of the slimes and water is obtained. In the construction of the tank an inner annular overflow is fixed at the top, the purpose of which is to receive and pass off the cleared water or solution rising as the settlement proceeds. A 3-inch pipe is fixed to the conical bottom of the tank, and through it are drawn off the settled slimes and water, the action of the tank being to concentrate the pulp from 3 per cent. of dry slimes at the intake to 30 per cent. of dry slimes at the discharge. The operation is quite continuous and automatic, the tank being capable of handling easily a flow of 40,000 gallons per hour of water, having an alkalinity of 0·02 per cent. If 1,000 tons of water, containing 30 tons of slimes, be delivered to the tank, by the time the 30 tons of slimes and its accompanying 70 tons of water have been discharged there will have been clarified and returned to the mill for immediate use no less than 930 tons of water, or more than 90 per cent. of the water received by the tank. Excepting that from the surface of 35 feet diameter presented by the tank, there are no losses by evaporation entailed in the system, and no losses by ground-soakage or leakage, and further, the cost of pumping is reduced to a minimum. This vat alone has reduced the water-losses on one mine by 400 gallons per ton of ore milled, namely from 600 gallons to 200 gallons.

Rock-Breakers.—The various types of rock-breakers are too well known to need description. They may be divided into the gyratory and movable-jaw types, each of which has its own particular functions. The gyratory machine is admirably adapted for breaking the rough ore as it comes from the mine, the fines having been separated out in the headgear grizzlies. Its chief claim to recognition lies in its capacity for reducing ore to a certain gauge, which is far greater than that of any other form of breaker, but the gauge should preferably be not smaller than, say, a 4-inch cube. If

fine breaking be attempted with it, there is not only excessive wear and tear on the cones and concaves, but it is also found difficult to keep the output at anything like a standard gauge. In practice the Author uses breakers of the gyratory type only for coarse or first-stage crushing, for which this type of machine has no rival. For reducing 4-inch cubes down to 2-inch cubes experience has shown that breakers of the movable-jaw type are best; the power required to operate them is less, the repairs are fewer, and the product is fairly even in gauge. They are, however, not successful as fine breakers, that is, for use in delivering a constant product of smaller gauge than 1-inch cube. For this purpose the type of crusher which

Fig: 34

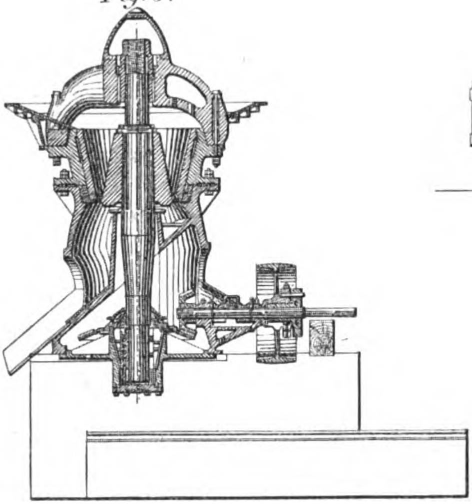


Fig: 35

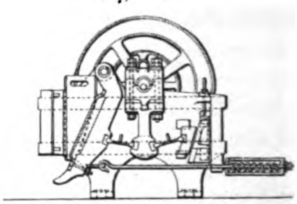
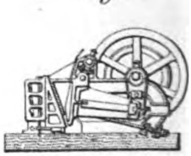


Fig: 36



maintains a constant opening between the fixed and movable jaw is better adapted, such as the so-called "roll-jaw" breaker. In this breaker, illustrated in *Fig. 36*, the crushing-jaw consists of a long lever swung from a link, instead of from one fixed point as in the Blake pattern. The driving end of the lever is reciprocated in the usual way by an eccentric shaft, connecting-rod and toggles. The lower end of the crushing-jaw rolls at a fixed distance from the fixed-jaw on the rock between them, thus reducing it to a product of uniform gauge. In *Fig. 34* is shown a machine of the gyratory pattern as a first-stage breaker, as arranged by the Author in a shaft headgear. A second-stage Blake-type breaker is shown in *Fig. 35*, and a third-stage constant-aperture, or roller-type breaker

in *Fig. 36.* The respective finished gauges of ore in the three stages are:—1st stage, 4-inch to 5-inch cube; 2nd stage, 2-inch to 3-inch cube; 3rd stage, ½-inch to 1-inch cube. The practical value of stage breaking has been demonstrated on two plants designed by the Author, the output of the stamps after the installation of stage breaking having increased in both instances by 15 per cent. to 20 per cent., at much less cost in capital and running charges than would have been required to obtain the same total output by increasing the number of stamps. In the following Table are shown the costs per ton for maintenance and power of a gyratory and a Blake breaker, the former doing first-stage and the latter second-stage breaking:—

Type.	Quantity Crushed.	Cost per Ton Milled for Repairs, Labour and Spare Parts.	Cost of Power per Ton.
	Tons.	Pence.	Pence.
Gyratory	103,000	1·141	1·616
Blake	212,000	0·572	1·012

The Tube-Mill.—The tube-mill (Figs. 37, Plate 5) consists of a sheet-iron revolving drum with cast-steel ends, b, b_1. It is lined with hard iron or steel liners or quartzite slabs, c, and contains a number of flintstone pebbles, d. The drum is rotated by means of a pulley and shaft, j, and toothed-wheel gearing, e, and is supported at the inlet-end by an ordinary bearing, and at the outlet-end by rollers, g. The ends are cast with hollow trunnions, which serve as bearers as well as inlet- and outlet-passages for the material. This material enters the drum at the driving-end by a suitable contrivance, f, is triturated by contact with the pebbles and the sides of the drum, passes out through a grating at the other end, and is discharged through the orifice, h, into a receiver, k. This machine was first introduced to the Rand for the fine grinding of ores on one of the mines under the technical control of the Author. The necessity of obtaining a more finely-ground product than that which could be economically obtained from the stamp-mill was forcibly illustrated in results secured from a long period of grading analyses made upon the mill-product by Mr. H. S. Denny, and subsequently communicated to the South African Association of Engineers.[1] The

[1] H. S. Denny, "Grading Analyses: some Indications and Deductions" Journal of the South African Association of Engineers, vol. x, No. 5.

analyses showed that the fine products from the mill readily yielded their gold, and the coarse products, which were poorest at the moment of leaving the mill and before being subjected to the treatment processes, were the richest in the residues. The inference was that if the coarse products were sufficiently finely divided, they too would yield their gold, and experiments conducted on this hypothesis fully confirmed it. The question then arose as to the best and most economical means of reducing ore to the fineness best conditioned for high extraction coupled with minimum time occupied in treatment. The methods evolved by Australian practice were considered to be most modern, and as in that colony tube-mills had been widely resorted to for sliming the ore, it was decided to experiment with them on the ores of these fields.

The first tube-mill on the Witwatersrand was erected at the New Goch Gold-Mines, and there exhaustive experiments were carried out both in fine grinding and in treatment of ores. The results of the experiments completely proved the capability of the tube-mill to produce a finely-comminuted product, but other features, to be referred to later, were not satisfactory. Attention was then directed to the possibility of reducing the ores for final treatment in the ordinary grinding-pan, and satisfactory evidence was forthcoming to show that the product of the pan would be eminently suitable for rapid, economical and efficient treatment by cyanide solutions. Comparisons made with regard to the prime cost, flexibility of units and maintenance-costs of the two machines also gave results in favour of the pans. The disadvantages of the tube-mill are:—(1) Heavy initial cost both for plant and for its erection; (2) inflexibility of the unit; (3) inaccessibility; and (4) loss of running-time owing to wear and renewals of liners. The first cost of a tube-mill to fine-grind, say, 70 tons of ore per 24 hours, is £1,500 erected in Johannesburg. The dimensions of this mill are 16 feet by 4 feet. Its charge of flint pebbles weighs, on an average, 4½ tons. It is lined either with special iron or steel castings, or with quartzite blocks, the latter in most instances being preferable. The cost for concrete foundations and pedestals for carrying the mill of course varies according to the circumstances; on a mill put down by the Author these items cost £300. In the Author's opinion the inflexibility of the tube-mill is one of its chief drawbacks. If a given mill is slightly overloaded and it becomes advisable to provide an additional mill to deal with the overload, the capacity of the two mills will be so much in excess of the work to be done that their efficiency will be very low, whilst the cost of power and maintenance will be correspondingly high. It must be remembered that a tube-mill cannot be run

faster or slower than its critical speed, which is determined to a nicety by the action of the pebbles within the tube. Should a mill run too fast the pebbles will be carried round with it by centrifugal force, and if run too slow they will lie as an inert mass on the bottom of the tube but inclined in the direction of rotation. The proper speed is attained when the pebbles are carried round to a point near the top of the tube and thence drop by gravity. The wear and tear of pebbles and liners, and the power required to rotate the mill, are therefore practically constant whether the mill is doing useful work or not. An obvious remedy is to put down very small mills, but so far these have not been manufactured; it is, however, probable that in the future they will be made of all sizes to overcome this objection. A list of the usual sizes and other particulars of tube-mills is given in the following Table:—

Size No.		1	2	3	4	5
Diameter of grinding-drum		3 feet 7 inches	3 feet 11 inches	3 feet 11 inches	4 feet 11 inches	4 feet 11 inches
Length of ditto . . .		13 feet 2 inches	16 feet 5 inches	19 feet 8 inches	23 feet 9 inches	26 feet 3 inches
Revolutions of ditto per minute		32	28	28	24	24
Diameter of belt-pulleys .		59 inches	78¾ inches	78¾ inches	78¾ inches	78¾ inches
Width of ditto. . . .		9⅞ ,,	10¼ ,,	10¼ ,,	10¼ ,,	11⅞ ,,
Revolutions of ditto per minute		160	110	110	140	140
HP. required (approx.) .		25	35	42	60	70
Output of ground ore in lbs. per hour (approx.)		4,400	6,600	8,800	11,000	15,400
Space required for mills with spur-gearing .	length	26 feet 7 inches	31 feet 6 inches	34 feet 9 inches	39 feet 5 inches	42 feet 8 inches
	breadth	8 feet 3 inches	11 feet 2 inches	11 feet 2 inches	11 feet 6 inches	11 feet 6 inches
	height	6 feet 11 inches	7 feet 11 inches	7 feet 11 inches	8 feet 3 inches	8 feet 3 inches
Price for complete machine without flints . . .		£370	£565	£605	£825	£900

As the mill consists of a closed tube, access to the interior can only be had after stopping, by means of a manhole cut in the outer shell, and as every manhole forms a possible seat of leakage only the minimum number is provided, generally not more than one. All inspection of the interior and all passage of liners and pebbles in or out, has to be done through this door. The time required to effect renewals of linings in the mill constitutes a serious objection to it. The average life of a set of liners grinding Witwatersrand ore seems to be not more than 12 weeks (in some instances it has been as low as 8 weeks), after which it is necessary to shut down the mill for a period of 6 to 8

days for renewals. As the tube-mill forms a link in a continuously-running chain it is imperative to provide a spare mill to take up the work whilst the first mill is under repair. Useful work can therefore be obtained from the spare mill during only, say, 1 week in every 13 weeks, and during the remaining 12 weeks it will be simply piling up interest charges.

With regard to the comparative cost and efficiency of tube-mills and grinding-pans, the following are the condensed results of working-trials in West Australia[1] under exactly similar conditions, using in the one case two 5-foot grinding-pans and in the other case a 13-foot tube-mill:—

BATTERY-PRODUCT BEFORE AND AFTER GRINDING.
Total product in each case, 82·16 tons per day.

——	Before Grinding.	After Grinding with Two 5-Foot Pans.	After Grinding with One 13-Foot Tube-Mill.
	Per Cent.	Per Cent.	Per Cent.
On 20-mesh screen	8·23	Nil	0·01
„ 40- „ „	28·78	0·88	6·15
„ 60- „ „	13·92	9·71	14·24
„ 100- „ „	13·74	26·60	23·14
„ 150- „ „	4·18	8·50	7·22
Through 150-mesh screen . . .	31·14	54·31	49·24

Deducting the 31·14 per cent. which passes through the 150-mesh screen, there is obtained from the original feed 56·57 tons of sand for regrinding, grading as follows:—

On 20-mesh screen	11·95 per cent.
„ 40- „ „	41·81 „ „
„ 60- „ „	20·22 „ „
„ 100- „ „	19·96 „ „
„ 150- „ „	6·06 „ „

The foregoing results were obtained by passing the whole of the products through the pans and mill once only, no return coarse sand being added to the original product.

The costs for equal grades of the ground products were:—

From the pans	2*s.* 3*d.* per ton of sand ground.
„ „ tube-mill . . .	2*s.* 6·7*d.* „ „ „

The ground product contained 70 per cent. silica and 5 per cent. sulphide of iron.

[1] See "Grit-Mills and Grinding-Pans." *The Mining Journal, Railway and Commercial Gazette*, 2 September, 1905.

The costs of running were:—

Two 5-Foot Pans.		One 13-Foot Tube-Mill.	
Power—13 I.HP. at 1s. 4d. per day	3·64 pence.	Power—20 I.HP. at 1s. 4d. per day	5·65 pence.
Shoes and dies	5·51 "	Flints and liners	3·74 "
Labour	0·50 "	Labour	0·58 "
Repairs and renewals	0·67 "	Repairs and renewals	0·63 "
	10·32 "		10·60 "

56·57 tons per day passed through in both instances.

The water actually passed through the pans amounts to about 1,600 gallons per ton of ore ground. The pans are run at a speed between 55 and 60 revolutions per minute, and absorb about 6½ HP. each.

The cost of the pans erected is about £250 each, ready for work. The following Table shows the chief points of difference between tube-mills and grinding-pans:—

	One 13-Foot Tube-Mill.	Two 5-Foot Grinding-Pans.
Capital cost (not including prime generating-plant)	£1,500	£500
Continuous power required	20 HP.	6½ HP. each pan.
Power per ton of output per 24 hours	0·353 HP.	0·229 HP.
Time required for re-lining	8 days	3 hours

the output being in each case 56·57 tons per day.

From the foregoing statements it is clear that the grinding-pan possesses some advantages over the tube-mill, and when the greater flexibility of pan-units is considered, it is evident that the use of the tube-mill is an expensive luxury.

Pulp Elevation.—The pulp as it leaves the mill is elevated to a sufficient height to enable it to enter the superimposed vats of the cyanide-plant. To effect the elevation of the pulp, various methods have been resorted to, namely, (1) pumping; (2) wheel-elevators; (3) bucket-elevators.

The pumps employed for the purpose of raising the mixture of water and slimes are almost exclusively of the plunger-type, arranged with a recess in the working-barrel for washing with water under pressure. The maintenance-cost of this type of pump has proved to be very high, amounting in some cases to more than 3*d.* per ton of pulp elevated, and their use has been discontinued in all recent mill arrangements. In isolated instances centrifugal pumps have been tried as a means of elevating the mill-pulp, but in

all cases the wear has been so great and the power absorbed so high that the pumps have been discarded.

In general practice the bucket-wheel elevator is used on the mines of the Witwatersrand. The usual form of wheel is one having wooden arms attached to a central cast-iron boss, with internal lifting-buckets fitted to the periphery in the usual way. Recent wheels of this construction have a diameter of 60 feet, and are carried upon built-up A-shaped steel frames, being driven by ropes run in a grooved driving-rim attached to the arms of the wheel. In view of the cost of these wheels—approximately £8,000 complete, made up largely of the high cost of labour in this country—the Author departed from the wooden structure, and employed a tangentially-spoked steel wheel. The wheel is rotated from a belt-pulley by an arrangement of toothed gearing at the axle. The cost of the wheel erected complete with steel staging, catch-boxes, etc., is £4,500, so that it shows a large saving over the locally-built wooden wheel. The power absorbed when lifting the pulp from 120 stamps is 21 HP. For moderate effective lifts, up to say 40 feet, the tailings-wheel is a most useful form of elevator for mill-pulp, despite the fact that in the larger sizes it is expensive to build. It does not absorb unreasonable power for driving, and the cost of maintaining it in an efficient state is not high. Tests recently made on a 40-foot wheel elevating 190 tons of mill-pulp per hour showed an average of 11·2 horse-power by ammeter-reading. At the average cost of power-production on the particular mine the cost per ton lifted amounts to 0·004 penny. This charge does not include interest.

The effective lift of a tailings-wheel is only about 82 per cent. of its diameter; consequently for effective lifts of 70 feet the tailings-wheel assumes such proportions as to make it economically impossible. In arranging for a lift of 70 feet in a plant recently designed the Author found it necessary to revert to some other scheme for elevating, and a bucket-elevator was employed. The speed of the belt is 590 feet per minute, and at this speed it elevates slightly more than 200 tons of mill-pulp per hour, at a rate of consumption of 30 HP. by ammeter-reading, which at the average cost of power-production on this mine, not including interest, amounts to 0·098 penny per ton of pulp lifted. It is too early yet to state the probable maintenance-cost of this plant, but it is not expected to be high. The cost of this apparatus, in duplicate, complete with motor for running, is £2,300, as against £12,000 for a tailings-wheel to give the same effective lift. The bucket-elevator has therefore a large margin in interest-charges in its favour, and

even although the maintenance-costs prove higher than for the wheel, they are not likely to approach the sum of the interest and maintenance-charges on the latter.

In some countries the elevation of tailings is done by air-lifts of the Pohle type, but these, with one exception, have not found favour on these fields owing to the cost of compressing air. In some parts of Transylvania the elevation of pulp is performed by bucket-wheels of small diameter delivering to one another in series. This can only be regarded as a complicated and expensive method, owing to the large power-consumption and the high percentage of slip.

Spitzlutte.—A type of spitzlutte in use on these fields is illustrated in Figs. 38, Plate 5. It is designed to take a flow of 300 tons of mill-pulp per hour, in which is contained about 27·5 tons of crushed ore. The spitzlutte is arranged to extract 33 per cent. of the tonnage entering it, together with about six times its weight of water, this water being required for the purpose of re-grinding. An average discharge from spitzlutten on these fields would be 10 per cent. to 15 per cent. of the ore passing through them.

Spitzkasten.—This apparatus, shown in Figs. 39, Plate 5, is employed for the separation of sand from slimes. It differs from the earlier "pointed" and pyramidal boxes in that the casing, *a*, which is built of steel plates and angle-bars, is wedge-shaped. Pulp enters by a launder, *a*, and is deflected downwards by a baffle-plate, *b*. The heavier particles are precipitated and discharged through a long narrow slot in the cast-iron catch-box, *c*. In the earlier pyramidal forms this orifice was either a square or a round hole. The lighter particles or slimes overflow at the outlet-lip, *d*. The principle involved in the design is the provision of a certain distance from intake to outlet in which the force of gravity may so assert itself that the heavier particles may fall through the flowing current and be discharged from the apex of the box. There is no uprising water-column to act upon the falling particles, so that the classification is not so good as in spitzlutten, although, if the operation be conducted in a sufficient number of successive boxes, practically the whole of the solids can be separated out from the water, thus clarifying the latter. The great difference, however, between the operation of spitzlutten and spitzkasten is that in the former a more or less perfect classification of material of the same specific weight is secured, whilst in the latter the separation is practically limited to separation of materials carried in suspension from those which will not remain in suspension in the spitzkasten. Thus a spitzlutten

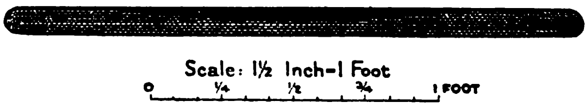
separation of ores containing 3 per cent. of iron sulphides will give a product containing 20 per cent. of iron sulphides, and the balance silica, whilst a spitzkasten separation of the same material would result in only a 4 per cent. to 5 per cent. separation of sulphide of iron, the remainder being silica. The shape of a spitzkasten, like that of a spitzlutte, is usually a modification of either the pyramid, the V, or the cone. The Author prefers the cone to any other form, as there is less liability of the material to become packed; there are no corners, the collection of the material for discharge is effected in the easiest and most natural manner, and, above all, the range of separation which can be effected is greater, on the basis of equal areas. In practice on these fields the working of the spitzkasten is so arranged as to ensure no settlement of slime in the box, and hence the areas are kept low, and the stream-velocities high. The object of preventing the settlement of slimes with the sands in the spitzkasten is to preserve an easily-leachable product for the sands-treatment tanks, as the inclusion of slimes tends to form impermeable layers which interfere with the gold extraction.

Conveyor-Belts.—The use of rubber conveyor-belts has come much into vogue on these fields during the last few years. They are used in the following operations:—

Ore-conveying and elevating.
Ore-sorting.
Removal and stacking of waste rock.
Elevation of sands between first and second treatment-vats.
Removal and stacking of sand residues.

The belt in most general use is one of five to seven ply, of best-quality heavy cotton duck, covered on one side with a layer of special rubber-compound, which in some cases is of a uniform thickness of $\frac{1}{16}$ inch right across the belt, and in others has a step reinforcement towards the centre, as shown in *Fig. 40*. It is necessary when

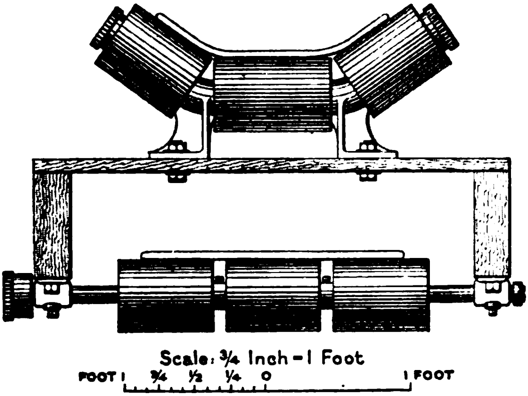
Fig. 40.



investigating the quality of a belt to do more than examine the rubber, because if this be laid on a poor foundation of duck, the belt, first through stretching and subsequently through dismemberment, will very soon be useless. The general construction of the belt-carrying and return idlers is almost identical in all makes. The carrying

idlers, as shown in *Fig. 41*, consist of a set of rollers, the outer inclined to the inner at an angle varying between 150 and 170 degrees. The inclination of the outer rollers is for the purpose of securing a troughed form for the belt when travelling. The return idlers, for carrying the return slack belt, are horizontal. The carrying idlers are spaced at intervals of 4 feet and the return idlers at intervals of about 10 to 12 feet. All idlers are provided with pressure grease-lubrication. In well-constructed belts most of the wear takes place at the break between the inclined and horizontal idlers—a fact which is tending to reduction of the inclination of the outer idlers. Except for elevating at fairly steep angles, where a certain amount of troughing in the belt is desirable in order to obtain a friction-hold on the ore, to prevent it from rolling, the Author sees no valid reason

Fig. 41.



why belts should not be run flat, if properly proportioned to the load. The width of the conveyor-belt is dependent upon the speed at which it is to be run. In the first large installations put down on these fields the tendency was to make the belts narrow and run them fast, but experience has shown that slow-running belts are more economical both in power and wear. The weight of a seven-ply belt is approximately $\frac{1}{4}$ lb. per foot length per inch width. The average breaking-strength of this belt is about 1,800 lbs. per inch width. The longest practicable length of a conveyor-belt, between centres, when working on inclines, is about 600 feet, as beyond this length there is danger of straining the belt, and also the head pulleys reach unwieldy sizes. The following are particulars of the diameter of head-pulleys required for belts of different lengths and sizes :—

Belt, 18 inches in width; lift, 40 feet; capacity, 100 tons per hour; speed, 375 feet per minute; tail-pulley, 18 inches in diameter.		Belt, 24 inches in width; lift, 60 feet; capacity, 125 tons per hour; speed, 175 feet per minute; tail-pulley, 24 inches in diameter.	
Length, Centre to Centre.	Diameter of Head-Pulley Required.	Length, Centre to Centre.	Diameter of Head-Pulley Required.
Feet.	Inches.	Feet.	Inches.
200	40 to 42	200	40
225	40 „ 42	225	42
250	40 „ 42	250	44
275	40 „ 42	275	46 to 48
300	44 „ 46	300	50 „ 52
325	46	325	52 „ 54
350	48	350	56
375	50 to 52	375	60
400	62	400	64

The following are the carrying-capacities of belts of various widths at a speed of 500 feet per minute, the material being sand :—

10-inch belt	35 tons per hour.
12-inch „	55 „ „
14-inch „	75 „ „
16-inch „	125 „ „
18-inch „	175 „ „

In the following Table are given particulars of the carrying-capacities of belts of various widths, at stated speeds, the material being ore of suitable gauge :—

Width of Belt.	At 200 Feet per Minute.		At 400 Feet per Minute.		At 600 Feet per Minute.	
	Largest Size.	Tons per Hour	Largest Size.	Tons per Hour	Largest Size.	Tons per Hour
Inches.	Cube.		Cube.		Cube.	
10	1½-inch	10	½-inch	25	¼-inch	35
12	2- „	15	½- „	50	¼- „	55
14	2½- „	25	¾- „	60	½- „	75
16	3- „	40	1- „	85	¾- „	125
18	4- „	50	1½- „	115	¾- „	175
20	5- „	75	2- „	150	1- „	250
22	5- „	95	2- „	150	1- „	350
24	6- „	125	3- „	250	1- „	475
26	6- „	160	3- „	325	1½- „	600
28	7- „	200	4- „	410	1½- „	750
30	7- „	250	4- „	500	2- „	900
32	8- „	300	5- „	600	2- „	1,100
34	8- „	350	5- „	710	2- „	1,300
36	9- „	450	6- „	850	2- „	1,500

An ordinary conveyor-belt carrying rock having a maximum gauge of, say, 5-inch ring, and running at not more than 200 feet to

250 feet per minute, cannot safely be run at a higher angle than 22° and is better kept at 20°, or at a rise of 36·4 feet in 100 feet. Doubtless, as the use of belts is further extended the special features of design necessary to render them useful at higher angles of inclination will be incorporated, but at present it cannot be said that the conveyor-belt is a practicable arrangement for inclines much steeper than 20 degrees.

The use of belts for sorting is daily increasing on these fields, and a plant designed for one of the mines is illustrated in Figs. 42, Plate 6. Ore is delivered from a vertical shaft A through the head-gear B, and tipped on to a grizzley C, where the coarse rock shoots to an ore-bin E, the smaller-gauge rock which has passed through the grizzley passing through the shoot D to the mixed-ore bin E. Ore from the bin G passes through six rock-breakers F, designed to crush to a 5-inch gauge. The crushed ore passes from the breakers into the bin G and is delivered to two conveyor-belts H, which convey it to the washing- and separating-house J. Here the ore is dumped on to a grizzley K and the fines are collected in an underlying bin M. The coarse ore is washed on plates L and is fed to two 40-inch conveying- and sorting-belts N. The washed ore is conveyed by these belts to the sorting-house P, where the waste rock is picked out by natives, standing in rows on four platforms 60 feet in length, one on each side of each belt. The belts travel at a speed of 60 feet per minute. The waste rock is thrown into the bins Q, whence it is conveyed by two 22-inch belts R to the waste-bins S, clear of the breaker-house, and thence is trammed to the waste-dump. The waste development-rock, which is hauled from the shaft, is tipped into the bins B_1, whence it is also trammed by the elevated track T to the waste-dump. The sorting-belts eventually deliver their loads of sorted rock to bins V in the fine-breaker station U. From the bins the ore passes through eight fine breakers W, where it is all reduced to 1-inch or 2-inch gauge, passing from the breakers into a bin X provided below for the purpose. The fines separated out at the washing-house are delivered by a fines-belt O to X, the same bin as the broken sorted ore. The bin X, containing the fines and sorted ore, feeds a conveyor Y, which conveys the ore to the mill and discharges on to a short travelling belt, which eventually discharges the ore into the mill bins.

The ore on its passage from the ore-bin X to the mill is automatically weighed by a Denison machine Z.

It is not, however, only for surface hoisting that the conveyor-belt can be utilized; it can be readily adapted to the conditions of mines and collieries. In one of the latter, in the Middelburg

district, the whole output is raised from the pit through a vertical height of 150 feet by a 30-inch belt on an incline of 19°. This belt has a length between centres of 525 feet, and is run at a speed of 380 feet per minute, carrying a maximum load of 250 tons of coal per hour. The theoretical power required amounts to 38 HP. and the actual to 50 HP., so that this plant has an efficiency of 75 per cent. It must, of course, be borne in mind that the special conditions of coal-beds at a depth of 100 feet to 150 feet from the surface are not frequently met with, and particularly favour the application of belt-conveyors for hoisting.

Running of Stamp-Mills.—The stamp-mill proper is usually in charge of a departmental head termed the mill manager, who is assisted in this country by white shiftsmen termed amalgamators, and a certain number of natives, depending upon the size of the mill. The mill manager is responsible for the running and general upkeep of the mill and for the efficiency of the amalgamation carried out. The running practice on the mines with which the Author is connected will be described.

Ore is delivered to the mill-bins from the sorting- and breaking-plants at a gauge varying between 1½-inch and 3-inch, rather less on mines upon which special fines-breaking plants have been installed and rather more on mines not so equipped. It is fed from the bins through suitably-arranged shoots to the ore-feeders, and is fed into the box according to the rate set by the millman. The mortar-boxes are of the straight-back pattern. Half of the boxes are fitted with 24-inch heads and the remainder with 18-inch heads, the longer heads having half-worn shoes and the shorter heads the newer shoes. As the latter wear they are transferred to the 24-inch heads and are there worn out, the object being to maintain as far as possible a uniform weight of stamp throughout the mill. The false bottoms on the mortar-boxes are of three different thicknesses, and upon them rest the dies, the newest on the thinnest and the most worn on the thickest liners. By this system the level of discharge is maintained practically constant in every mortar-box. In some cases the same object is attained by using screen-frames fitted with sills of different depths. The tappets are set to give an average drop of about 8½ inches. The discharge from the box is never allowed to become higher than 2 inches above the level of the die-top. The screen-frames are of the usual wooden type, keyed to the discharge-opening by suitable gib-keys. The inclination of the screens is, however, as far as permissible by the working conditions of the mortar, inwards, instead of outwards as in the universal practice. This alteration added appreciably to the output per stamp.

The screens used have 200, 400 and 600 holes per square inch, and woven wire screens are preferred to any other form. The variation of the coarseness of the screen is due to the difference in the design of the treatment-plant as a whole. The modern plants are all provided with re-grinding machinery, either tube-mill or pans, and therefore crush in the battery to 14-mesh (200 holes per square inch) only, whilst the old plants with only small re-grinding facilities are working with the fine mesh. The tonnage crushed by a 1,200-lb. stamp, working on ore broken to a 2-inch ring-gauge, with different screens, is as under :—

With 200 holes	per square	inch	each stamp	crushes	6·5	tons.
„ 400	„	„	„	„	5·7	„
„ 600	„	„	„	„	5	„

If the ore be delivered to the stamps broken to a 1-inch ring-gauge the output per stamp will be increased by not less than 10 per cent. Water or cyanide solution, as the case may be, is fed into the back of the mortar at about the level of the dies. The amount of water or solution required is, on an average, 10 tons per ton of ore crushed. The temperature of the water or solution should not exceed 85° F. As the pulp is discharged from the screens, samplings are taken at regular intervals of 20 minutes throughout the day. The plates are scraped each morning. Only the upper third of the plate is scraped daily, but this yields at least 90 per cent. of the total amalgam. Whilst this scraping is in progress, natives are at work dressing the lower sections of the plate. The time occupied by the whole operation amounts to 10 minutes per plate per day. Great differences of opinion exist among mill-men as to the relative advantages of steaming or scraping the amalgamated plates for the purpose of securing the adhering gold amalgam. The steaming of the plates is done by introducing live steam into a shallow box laid over the amalgamating-tables, and thereby subjecting the amalgam to a species of sweating. The effect of the operation is to render the amalgam on the plates quite pasty, thus enabling it to be easily removed from the underlying copper. The operation of "scraping" is performed by means of chisels and specially-made knives, by which the hard adhering amalgam is removed from the copper plate. Before scraping, if the amalgam be unusually hard, the surface of the amalgamated copper may be scoured by rubbing it with sand and a solution of cyanide or sulphuric acid. The disadvantages of the steaming method are that it leaves the plate-surface very bare of gold, and in this condition it does not catch gold so readily as when there is a good coating of amalgam. In consequence, the percentage of gold caught on the plate will always

drop for the first few days after steaming, and as amalgamation is the cheapest process of gold recovery this results in ultimate loss. The advantages of scraping plates as compared with steaming are: (1) the percentage of recovery is kept more uniform; (2) there is less danger of theft from the plates, as there is no great accumulation of amalgam; and (3) the plates are always in good condition for gold recovery. The Author employs the scraping method on all the mines under his control.

Other sources of amalgam are traps, screens, die-sands and washings, which are periodically cleaned up, their yield being added to the total. The amalgamated plates are usually about 72 square feet in area for each battery of five stamps, and in a modern mill approximately 25 tons of ore are passed over the amalgamated surface per day; hence there is a plate-area of roughly 3 square feet of amalgamated plate for each ton of ore crushed per day. That this is ample may be judged from the fact that the amalgamating-plates attached to a high-speed stamp-mortar, running under similar conditions of ore, feed, etc., showed an equally high percentage of gold caught, although the plate-area is only roughly 2 square feet of surface per ton of ore crushed per day. The percentage of amalgam caught in a mill on the Rand will, of course, always vary. The fineness of mesh used on the mortar-box has a considerable influence on the quantity of gold released from the quartzite matrix; the finer the screen-mesh, the higher will be the percentage of gold caught on the plates. Under average conditions, about 65 per cent. of the total gold from all products fairly represents the gold won by amalgamation, the actual percentage varying between 55 per cent. and 75 per cent.

The following figures show actual results obtained from one of the producing mines with which the Author is connected:—

The total quantity of ore milled during the month to which these figures refer was 11,250 tons.

Total amalgam recovered	9,745 ounces
Total mercury used	6,875 ,,
Amalgam produced per ounce of mercury used	1·417 ounce
Mercury lost on 11,250 tons milled . . .	716 ounces
Retorted gold	3,615 ,,
Smelted gold	3,587·19 ounces
Difference of weight between retorted and smelted gold = 0·775 per cent.	27·81 ounces
Fine gold in amalgam	32·415 per cent.
Total fine gold	3,131·903 ounces
Fine silver in bullion	530·29 ounces

The day is divided into three 8-hour shifts, and all details of work are carefully recorded in the mill log-book.

The following is a detailed statement of the milling-costs on a mine running 160 stamps, for the month of July, 1905 :—

	Cost.			Cost per Ton
	£	s.	d.	Pence.
European wages	378	1	8	4·058
Shoes	89	6	6	0·958
Dies	44	2	0	0·473
Stems	8	0	0	0·086
Tappets	20	0	0	0·215
Cam-shafts	8	0	0	0·086
Belting	18	9	0	0·198
Feeder spares	7	8	0	0·079
Iron—bar	4	15	6	0·051
Lubricants	11	18	10	0·128
Mercury	17	2	6	0·184
Rope	9	18	4	0·106
Screens	49	11	5	0·531
Steel—bar	2	4	2	0·023
„ sheet	6	6	0	0·067
Sundry	37	15	3	0·405
Timber	15	8	5	0·165
Lime	40	0	0	0·429
Pipes and fittings	2	12	0	0·028
Chinese wages and food	48	13	6	0·522
Native „ „ „	128	9	1	1·376
Steam-power	830	0	1	8·900
Workshops	122	18	0	1·318
Electric light	53	3	4	0·570
Assay office	13	11	7	0·146
	1,967	15	2	1s. 9·102d.

Sands-Treatment Plant.—The usual arrangement of a sands-treatment plant, in which one set of vats is superimposed above another set, is shown in Figs. 43, Plate 6, the upper set being the first treatment-vats and the lower the final treatment-vats. There has been a tendency recently to arrange both the first and the second treatment-vats on a common level, in order to economize staging, the sands being conveyed and elevated from the first set to the second by belts. Such an arrangement, however, is hardly likely to be generally adopted, since it involves some complication in working. Referring

to Figs. 43, Plate 6, the pulp from the mill enters the spitzlutten A, which discharge their concentrates to tanks specially reserved for the treatment of that product. The overflow from the spitzlutten passes down the launder B to the spitzkasten C. The sands from the spitzkasten C are distributed through branch-pipes, radiating from a pulp-distributing tank to the upper or settling-tanks D, the pipes being fitted with a short length of flexible hose with a clip for shutting off the supply. As much water as possible is drawn off through adjustable overflow-gates, the lip of which is always kept slightly above the level of the sands, and passes along the launder F to the return sands spitzkasten G. Solution is pumped on to the sands through the pipes K, and is decanted through leaching-pipes H at the bottom of the tanks, passing through a filter-bed of cocoa-nut matting. The sands are discharged through the bottom of the upper tanks into the lower set E by means of discharge-doors L. More solution is pumped on, and after draining the sands are thoroughly washed with water, being finally discharged at the bottom into trucks. The leaching-solution in every case passes on to extractor-boxes. The tanks are all of mild steel, and are raised on steel columns and joists resting on masonry foundations. A wooden platform is fixed round each tank. The upper settling-vats are shown in detail in Figs. 44, Plate 6. The discharge from the spitz-kasten, consisting of water, sand, and a portion of the slimes, is delivered into the settling-tank A. The framing B is laid on the bottom of the tank, and upon this slats C are laid crosswise. Over the slats C is laid cocoanut and jute matting D, which acts as a filtering medium for the solutions. Over the matting it is usual to place slats to facilitate the shovelling of the sands to the discharge-doors. The sands after settlement and preliminary treatment are passed through discharge-doors E. Three canvas roller-blind gates F are fixed to the inside of the tank to regulate the discharge of the separated water and slimes from the settled sands, the overflow passing through the door G. The tank is supported on cast-iron columns, on which rest bearers and joists. Wooden decking is laid on the joists, for the purpose of cushioning the vat. The columns are braced together by tension-bolts.

The main objects to be aimed at in the design of sands-treatment plants are:—concentration of supervision; ease of manipulation of solutions; rapidity in emptying vats; satisfactory disposition of flood-gates in the upper or receiving-vats, combined with an easily-worked opening and closing arrangement; large filtering-area; and ample capacity, to ensure sufficient time for treatment. It has been urged by metallurgists as an objection to the design shown in

Figs. 43, Plate 6, that some of the columns carrying the upper vats are placed within the lower vats, it being maintained that the periphery of each column would set up a kind of short-circuit in the solutions, to the prejudice of the general extraction. The obvious reply to this is that the combined surface-area presented by the columns is so small in comparison to the area of the sides of the vat in contact with sand as to render their effect as percolating-channels practically negligible. In subsequent practice with plants of this design, no difficulty has been experienced in obtaining satisfactory gold-extraction. The alternative design provided for the carrying of the upper vats on heavy built girders spanning the lower vats and carried on outside columns. These girders, by reason of their great weight and consequent high freight and transportation-cost, proved a very expensive form of construction, and hence the design shown in Figs. 43, Plate 6, was adopted. The upper or receiving-vats of the sands-plant are always made of smaller area than the lower, for the reason that the sand packs closer during the original filling in the presence of water than it does when transferred dry through the discharge-doors of the upper into the lower vats. The usual dimensions of the upper vats are 40 feet in diameter by 8 feet in depth, and of the lower vats 40 feet in diameter by 9 feet in depth.

In considering the general design of sands-treatment plants, the first impression conveyed will probably be the absence of mechanical arrangements for handling the sands. The Author had in mind at one time the idea of introducing canting vats for the more ready removal of the sands, in substitution of the present laborious and costly method of hand-shovelling through the several discharge-doors provided. Working along these lines, however, soon suggested the view that if all the ore could be reduced to the consistency of slimes, the whole of it could be readily removed from vat to vat by means of hydraulic head, and could be subjected to treatment during the natural agitation involved in its passage from the one to the other. This led to the design of the slimes-plant described later. Working results obtained from a plant of this design show that the gold from finely-ground ore can be quickly and economically extracted. The Author's present attitude in the matter is that no sands-plant is required for the treatment of Witwatersrand ores, since a plant far less costly in erection and working has been evolved. The comparative first costs of the two systems can be readily appreciated if it be considered that in the sands-plant large areas of tanks must be provided, first, for the storage of the sands prior to their treatment, and second, for their treatment, and incidentally that much time is absorbed in the various processes of filling, treating and emptying.

In good practice a charge of sands in the tanks occupies 6 days to 10 days in treatment, from the time it is received in the sands-plant until it is discharged to the residue-dumps. In the plant designed for the continuous treatment of the finely-ground ore, on the contrary, the charge is always moving forward, and is actually in the plant for a period of less than 24 hours, whilst its transference from vat to vat is accomplished automatically. It is clear, therefore, that the area required by the new system is only a small fraction of that required by the old, and hence the capital costs are greatly reduced.

The "Clean-up."—The "clean-up" of a cyanide plant is an operation requiring skill, patience and activity. As it is an important feature of cyanide-plant work it will be described somewhat in detail.

All preparations should be completed on the day previous to the clean-up. These comprise putting together and testing the filter-press, putting a certain amount of water and acid into the acid-tank, and getting buckets, shovels, sponges, hoses, etc., all ready for expeditious work, so that no unnecessary delay may occur after the boxes have been started upon. It is sometimes advisable before commencing the clean-up to increase the strength of the solution in the strong boxes by the addition of cyanide at the head; then to stop the flow of solution and allow the strengthened solution to work on the contents of the box for a time. This will be found to loosen the gold from the zinc considerably. The strong solutions in the boxes should then be displaced with water, or, if this will increase the stock of solution too much, with the weakest solution available. The clean-up of the strong-solution extractor-boxes is then commenced. Where a filter-press only is in use, the suction-hose, having a "rose" on the end, is inserted into a corner of the top compartment, and the solution is pumped out down to the screen of the false bottom, this operation being performed with each compartment in succession, with the exception of a compartment about the middle of the extractor-box, in which all the coarse zinc from the other compartments is rinsed, the screen remaining in this compartment during the process of rinsing. Any zinc which is considered to be too fine to be returned to the boxes because of its liability to choke the screens, where the boxes are small, is taken direct to the acid-tank. In an ordinary plant the washing of the zinc in a compartment of the extractor-box is better than carrying a large bulk of it across to a washing-tub, as the chances of mechanical losses are less. After removing all the coarse zinc and screens from the box, each compartment is washed down and is then pumped as dry as possible by the filter-press pump. The remaining slimes and

solution are transferred to the acid-tanks for treatment. The same routine is followed on each extractor-box in succession, in the order of their strengths. The screens, after being properly washed, are replaced in the compartments, and are first covered to a depth of a few inches with the coarsest zinc. The finest and richest zinc which has not gone to the acid-tank is then placed on this, always commencing at the top compartment of the box, the object being always to concentrate as much of the gold as possible at the head of the strong-boxes. In dressing the compartments, care must be taken to distribute the zinc evenly, pressing it slightly into the corners and sides. It is of great importance that the moist zinc should be exposed to the atmosphere for as short a time as possible, as it rapidly oxidizes, causing losses of zinc and cyanide, and inferior precipitation. The time occupied in the actual cleaning-up of the boxes is much increased by the slow work of the filter-press pump, and this is also a cause of the zinc being exposed to oxidizing influences for an unnecessary time. A 2-inch centrifugal pump with a hose-attachment would take the same amount of solution to a storage-tank in about one-sixth of the time, and from this vat the filter-press suction could work, when not actually required in the boxes, and after the boxes had been re-dressed and the solutions were running again. The delivery-hose from the filter-press should reach to the head of a working-box during all these operations. All the "coated" zinc on hand is used up as far as possible in dressing the stronger boxes, and the remaining compartments are dressed with new zinc. All new zinc going to the weak boxes is first immersed in a solution of lead acetate, until a dark grey colour is imparted to the zinc. An excess of this lead salt gives trouble in the reduction of the zinc by sulphuric acid, and causes impurity in the resultant bullion. It is important that the zinc in the boxes should be kept in good clean working order, by getting rid of some of the impurities in the solution. When these impurities become precipitated in the boxes, a large bulk of poor zinc-gold slime is obtained, having a low percentage of fine gold, which has a direct bearing on the consumption of sulphuric acid, coal, crucibles, liners, fluxes, and lime, and also on the amount of bye-products, and of gold finally left in the bye-products. When all solutions from the boxes have passed through the filter-press, it is opened and cleaned out, and the contents are fed slowly into the acid-tank, this product always being the last to be treated with acid.

Quantity of Acid used.—Theoretically, the amount of acid to be used for the reduction of zinc is 3 parts by weight of pure acid to 2 parts by weight of zinc, but in a "clean-up," where the product to be

acid-treated is so variable in composition, the process of estimating the percentage of zinc is one of extreme difficulty, and it is not possible to pre-determine accurately the amount of acid required. In some plants practically slime only is removed for the "clean-up" each month, all "fines" after washing being returned to the boxes, while in others a considerable amount of "fines" has to be reduced. The amounts of these two products vary with the size of the extractor-boxes, the value of the ore treated, and the strength of the solutions in use. A 3-gallon bucket full of "slime" may weigh 50 lbs. and contain 30 per cent. of moisture and very little free zinc, whilst the same bucket full of "fines" may weigh 25 lbs. and contain 10 per cent. moisture and the balance in great part free zinc; therefore the estimation of the amount of zinc in the varying products with any degree of accuracy is very difficult. The gold-slimes should be handled as little as possible, as each handling increases the chance of loss. The best method of conducting the acid-treatment is in the first place to have the acid-tank of comparatively large size; it is filled two-thirds full of water, and 100 lbs. of sulphuric acid is added; into this weak solution the zinc is fed carefully, and at intervals more acid is added, the agitator being kept moving continuously, and the acid being always slightly in excess. This procedure is followed until action practically ceases. When this is observed, a portion of the solution of zinc sulphate is drawn off, water and a little more acid is added, and probably further considerable action will ensue. This is a point to be carefully watched, because, if a large quantity of zinc be first placed in the acid-tank with a limited supply of water, and acid be then fed in, not only does very violent action occur, but very soon the solution becomes "saturated," the zinc sulphate partially crystallizes and forms a protective coating on the zinc, and very low efficiency is obtained, even from a large amount of acid, if added when in this state. If, however, the solution be drawn off as before described and the mass be washed by agitating with clean water, and a small quantity of acid be added, its action is immediate. Thus two separate operators working on the same product may get a very different efficiency from a given quantity of sulphuric acid. After all the zinc has been reduced, the zinc sulphate is washed out by repeated dilution and decantation until the solution is about neutral, decantations from the lower tank being constantly tested for suspended matter. The filter-press is now coupled to the acid-vats, and their contents are drawn off into the press, the acid-tanks being thoroughly cleaned out. For about ½ hour after the acid-vats have been emptied, the filter-press is run on air, after which it is opened and drained. The slime-cakes are now taken out and placed in

calcining-trays, a small quantity of nitre being added to get rid of any sulphate remaining. The press-frames and cloths are sponged over to get off all the adhering slime. All through the operations extreme care is taken that all utensils used are kept thoroughly clean, and the operators' hands are frequently rinsed. The trays containing the gold-slime in the moist state are then conveyed to the calciner. The heat is very gradually raised until the contents are just a very dull red; they are then taken out, cooled, weighed, mixed with fluxes, and carefully charged into crucibles having clay liners, a light cover of borax being added to prevent dusting in the furnace. The most useful flux for ordinary gold-slimes consists of:—slime, 100 parts; fused borax, 35 parts; sand, 20 parts; manganese di-oxide, 10 parts; fluor-spar, 5 parts. The crucibles containing the gold-slime are now placed on the hearth of the reverberatory furnace, this having been previously covered with a layer of coarse bone-ash, where they remain for about 3 hours, the temperature being gradually raised towards the end of the operation. The crucibles are then withdrawn and the contents are poured into large conical moulds. When the slag has cooled sufficiently, the moulds are inverted, the gold buttons are detached and placed in a hot No. 20 plumbago crucible in an ordinary Cornish furnace. This crucible should contain a little borax, and should stand flat on a brick having a layer of bone-ash, otherwise there is danger, at the high temperature used, that the underlying coke may pierce the pot. When the button is melted, a little bone-ash is added to thicken the slag and absorb the base metals, the slag as a whole being subsequently skimmed off the surface of the metal. If dip-samples are taken, they are obtained at this stage. The gold is then poured into a hot, lightly-oiled mould. After a short time the bar is taken out and placed in an acid-bath for about one minute, then taken out, washed clean, dried, sampled, numbered and weighed. All slags, liners and crucibles are examined for prill of gold, and any unfit for further use are crushed in a slag-mill, panned off, and stored until sold. In the Table on p. 288 is given a detailed statement of the sands-treatment costs in a mine running 160 stamps for the month of July, 1905.

Slimes-Treatment.—The average quantity of slimes produced in crushing the ordinary banket-ore of the Rand ranges between 20 and 30 per cent. of the total ore milled. The average value of the slimes bears a well-defined relationship to the original gold-content of the ore; that is to say, an ore yielding 40*s.* per ton milled will produce slimes assaying probably 3½ to 4 dwts. per ton, whilst an ore yielding 25*s.* per ton will produce slimes assaying probably 1½ dwt. to 2 dwts. per ton. The method of slimes-treat-

	Cost.	Cost per Ton
	£ s. d.	Pence.
European wages	265 13 6	2·848
Contractors	427 18 4	4·589
Cyanide	357 12 9	3·835
Chemicals	58 17 10	0·631
Lime	21 5 0	0·228
Lubricants	5 10 8	0·059
Rails	1 1 11	0·013
Trucks	14 7 6	0·155
Truck-wheels and bearings	9 12 6	0·104
Timber	3 13 9	0·039
Zinc disks	104 13 6	1·123
Sundries	68 4 8	0·731
Belting	14 0 0	0·150
Chinese wages and food	158 16 0	1·703
Native " " "	67 11 0	0·724
Steam and electric power	135 6 4	1·451
Workshops	91 16 4	0·985
Electric light	9 13 5	0·104
Assay office	39 19 10	0·428
	1,855 14 10	1*s*. 7·900*d*.

ment most generally in use on these fields is known as the "decantation" process, in which vats of 700 tons capacity are used, the slimes are agitated and transferred from vat to vat by centrifugal pumps, and the separation of slimes and gold-solution is made by allowing lengthy time for settlement at all stages of the operations, subsequently decanting the cleared solutions by means of float decanting-heads. The capital outlay in connection with the plant is so high that, according to the Author's calculation, the amount which should be written against charges on account of interest, depreciation and amortization, is not less than 1*s*. per ton of slimes treated. This constitutes such an obstacle that the Author could not recommend the adoption of the system. The working-costs range between 2*s*. 6*d*. and 4*s*. 6*d*. per ton of slime treated. As the value of a 2-dwt. slime is only 8*s*. 5*d*. and only 70 per cent. extraction can be counted on by this method, the yield on this grade of slimes would only barely balance the charges. The average cost of a decantation slimes-plant erected, including a proportion of the extractor-house cost, is between £150 and £180 per stamp; that is, a slimes-plant

for a 200-stamp mill might be expected to cost £35,000. The slimes-plant designed by the Author and shown in Figs. 45, Plate 6, was specially arranged for low capital and working cost. A plant recently erected to treat the slimes from 120 stamps cost £7,000. The charges on account of interest, depreciation and amortization would amount, on the same basis as the previous calculation, to rather less than 3*d.* per ton, and the working costs to 1*s.* 8*d.* per ton of slime treated. In the plant shown in Figs. 45, Plate 6, the slimes concentrated in the vat F from 3 per cent. to 30 per cent. solids in the pulp are delivered to vats AA′. In these vats a further concentration is attempted, but the percentage of increased solids rarely exceeds an additional 5 per cent. The separated water representing the increased concentration from the discharge of these vats is returned to the return-water tank S. The discharge from the vats AA′ of 35 per cent. solids is delivered to vats BB′, meeting a stream of cyanide solution at the vat intake sufficient to make about 3 tons of cyanide solution per ton of slimes under treatment. The rising cleared solution from BB′ is now gold-bearing, and is sent direct to the gold extractor-boxes. The continuously discharging pulp from BB′ is delivered to CC′ where it meets at the intake with a weaker solution of cyanide. A similar separation in these vats sends a clear overflow gold-solution to the extractor-boxes, and discharges continuously to DD′. In these vats a similar separation is again effected, the discharge from the vats going direct to filter-presses, which save the gold-solution remaining in the discharged residues. The average extraction from a 2-dwt. slime at present under treatment by this plant is more than 80 per cent. All processes of transference from vat to vat, separation of solutions from solids, and agitation of solutions of the gold, are performed continuously and automatically, in contradistinction to the decantation method, in which all transference and agitation is done by centrifugal pumps, which experience has shown to be high power-consumers.

General Reduction and Treatment Scheme.—The most recent reduction and treatment scheme designed and carried out by the Author is illustrated in Fig. 46, Plate 6. The ore coming from the mine is delivered through a grizzley by means of the shaft headgear A to the floor above the preliminary breakers A_1, shown to a larger scale in *Figs. 34*. Here it is subjected to scrutiny, and any large pieces of quartzite free from adhering reef-matter are immediately rejected and thrown into a waste-rock-bin. The ore proper is fed into the gyratory breakers shown, and is reduced to a minimum gauge of 5-inch ring. From the breaker it passes to a bin below and is thence transferred by a conveying-belt A_2, 24 inches in width and

travelling at 180 feet per minute to the top of the sorting-house B. The belt discharges its load on to a grizzley set to 1½-inch gauge, the fines passing through into a fines-box, whilst the coarse ore shoots into a bin. From the latter the ore is discharged into a washing-trommel B_1, shown to larger scale in Figs. 47, Plate 6. The trommel is composed of a cylinder of steel grizzley-bars *a*, secured in place near each end by two inside rings *b*. On the outside of the bars are two steel bearing-rings *c* and shields *d*, and at the higher end a cast-steel driving-ring *e*, engaging with the driving-pinion *f*. The trommel is inclined at an angle of 15 degrees to the horizontal, and is mounted on four rollers *g*, the bearings for these rollers being carried on cross-channels *h*. The whole frame is supported on four cast-iron columns *j*. The mixed ore enters the trommel at the higher end, the fine ore passing through the grizzley-bars to the ore-crushers, and the coarse ore discharging at the lower end on to the sorting-table. The object of this trommel is to permit a gradual delivery of the ore to the sorting-table, B_2, the ore in passing through the trommel being thoroughly washed and all adhering fines washed off, and through perforations made in the trommel for the purpose. The water and fines from the trommel may either be led to collecting-pits and subsequently sent to the mill, or, if sufficient fall can be obtained, may be sent direct to the mortar-boxes. The ore, after delivery to the sorting-table, slowly revolves past a number of "sorters" stationed both inside and outside the sorting-platform, whose duty it is to lift from the tables any pieces of rock which do not contain pebbles, and dispose of them in properly-arranged bins C_1, placed both within and without the revolving table. After having passed the sorters stationed round the table, the sorted ore is automatically swept off the surface of the table into shoots, which lead to the second-stage rock-breakers B_3 shown to a larger scale in *Fig. 35*. The scrapers are set on the surface of the table tangentially to its direction of rotation, and thus direct the ore into the shoots. The rejected waste rock from the bins C_1 is trucked out from the bottom and elevated for dumping.

Sorting Tables.—The operation of sorting, as practised on these fields, is directed to the rejection of worthless quartzite—colloquially known as "waste rock"—which is broken during the process of mining. Opinion in the past has been greatly divided as to whether revolving sorting-tables, or belts as shown at N in Figs. 42, Plate 6, offer the greater advantages; but with the more extended experience of belts the consensus of opinion would, the Author believes, be in their favour, in positions in which their construction and running would not be hampered. The circular sorting-table, shown in Figs. 46, Plate 6, is 30 feet in diameter, 4 feet in width, and 2 feet $11\frac{3}{16}$ inches

above floor-level, mounted on twelve cast-steel grooved path-rollers. The table is turned by means of a rack and pinion, and is kept steady and in correct position by six horizontal guide-rollers. The cast-iron rack is bolted in segments to the under side of the table. The special advantages of a revolving table lie in the fact that it is easily arranged in a small space and can be fitted into a building of moderate size, as shown in Figs. 46, Plate 6. A table 30 feet in diameter revolving at the rate of 35 feet per minute will easily handle all the ore passing over it to feed a mill of 120 stamps. The percentage of waste rock lifted from the table will of course depend entirely upon the proportion of reef to waste passing over it. It may be pertinent to remark here that the ore which passes over a sorting-table rarely exceeds 60 per cent. of the total milled, the balance being "fines," which have been automatically separated at different points on the grizzlies. The statements sometimes made by mining companies that they sort up to 45 per cent. of the ore milled must therefore be accepted with reserve, since that would mean approximately 75 per cent. of the ore fed to the sorting-table. The average cost of sorting, conveying and breaking per ton of ore milled amounts to 1*s.* 3·802*d.* The following is a detailed statement of the actual expenditure on sorting, crushing and transport in a mine running 160 stamps, for the month of July, 1905, the total quantity of ore crushed being 22,380 tons:—

	Cost.			Cost per Ton.
	£	*s.*	*d.*	Pence.
European wages	126	17	3	1·359
Belting	100	2	2	1·073
Crusher spares	86	6	6	0·926
Lubricants	27	14	0	0·297
Ropes	9	18	4	0·108
Truck-wheels and bearings	13	0	0	0·139
Sundries	69	0	9	0·740
Steel—bar	26	0	10	0·279
" sheet	14	11	5	0·156
Chinese wages and food	367	13	1	3·942
Native " " "	222	12	0	2·388
Steam and electric power	144	12	5	1·553
Workshops	250	11	7	2·687
Electric light	14	10	0	0·155
	1,473	10	4	1*s.* 3·802*d.*

After passing the second-stage breakers, to the bins C, the sorted ore is elevated by the elevator D in trucks to the third-stage breakers E_1 shown to a larger scale in *Fig. 36*, and is reduced therein to ½-inch gauge, falling thence to an underlying ore-bin E_2. From this bin the ore is conveyed and elevated by a belt E_3, and deposited in the mill-bins. An elevated tank for the mill water-supply is shown at M, and in greater detail in *Fig. 32*. The mill-house is shown in cross-section at F, showing the stamps back to back, and the ore-bins arranged for feeding the mill. The ore is fed through the stamps and is conveyed direct to a spitzkasten, the overflow of which is led to the amalgamating-table H. The discharge from the bottom of the spitzkasten is delivered directly into the tube-mill G. The ore, after passing the latter, is discharged into the spitzlutten shown, the overflow from which passes on to the amalgamating-tables H, and the bottom discharge from which, representing particles of ore not sufficiently reduced, is returned to the elevator shown and passed again through the tube-mill. The pulp flowing from the amalgamating-tables passes through mercury-traps placed at the foot, and is conveyed thence into large conical separators J′. Cyanide solution is the medium employed throughout for carrying the ore; hence the separated solutions from J can be taken through the clarifying-tanks P to the extractor-boxes, or, if water be circulated, it is discharged into the return mill-tanks K and pumped back to the mill supply-tank M by the pump L. The discharge from the bottom of the conical separator J is pumped by pumps N into the slimes-treatment plant Q. As this plant, both in design and operation, presents original features, it will be described in detail.

Slimes-Treatment Plant.—A continuous and automatic slimes-treatment plant erected to the Author's designs is illustrated in Figs. 45, Plate 6. The object of the departure in this design was to secure a gravity-system of transference of the material from vat to vat, concurrently with concentration of the solids in the vats and separation of the cleared solution. Two so-called separator-vats F F, the upper portion of which is cylindrical and the lower portion conical, receive the whole of the water and slimes from the mill by the launder E into a central intake, shown in the plan, which is suspended from two girders across the vats and extends downwards for about 6 feet. The incoming slimes and water may amount to 40,000 gallons per hour in each vat. The action in the vat causes a natural separation of the matter in suspension from the solution, the suspended matter falling to the bottom, to be there discharged, and the solution, cleared of suspended matter, continuously rising and

being discharged into an annular launder for ultimate delivery by the launder G to the clear-water tanks S. The amount of solids entering these vats is, on an average, approximately 3 per cent., whilst the solids in the discharge vary between 25 per cent. and 30 per cent. The discharge is led away by a pipe H and delivered into the pump-sump J. From the sump J special diaphragm slimes-pumps K pump the material by the pipe L into the vats A A′. These vats are similar to the vats F F, except that they are of smaller capacity. The material from the sump J, containing 25 per cent. to 30 per cent. of solids, is received in the cylindrical intake shown in the plan, and in these vats a further concentration is effected, namely to a discharge containing 35 per cent. to 40 per cent. of solids. The separated water in A A′ rises to the top annular overflow and is discharged through the pipes Q to the clear-water tanks with the overflow from F F, whence it is delivered by pumps T through pipes V to mill-tanks and launders N. The material from A A′ is then delivered through pipes M and launders N to the cylindrical intakes of B B′, where also a quantity of cyanide solution meets the pulp and flows with it into the vats. The operation of settlement and separation in these vats is exactly similar to that in the first vats, but the important difference is that, whereas in the first vats the slimes were only in contact with water, in these the slimes are in contact with cyanide solution, which is supplied through pipes R. The overflow of cleared solution, instead of being water, is now cyanide solution containing gold, which flows through pipes P to the gold extractor-boxes. The same process of separation is carried on in C C′ and D D′, but in these instances the strength of the cyanide solution is so very low that the final effluent from D D′, containing, say, 40 per cent. solids and 60 per cent. solution, has been as far as possible depleted of its gold value. Reference will be made later to the method of dealing with this discharge.

The novel features of this design are the method of utilizing natural means for the separation, and gravity for the passage of the material under treatment from one vat to another, thus obviating expensive plant for storage and settlement purposes, and the enormous cost of pump-transference from one vat to another.

On p. 294 are given particulars of the actual treatment in one of these plants for the month of July, 1905.

The capital cost of this plant is less than half of that of a plant of equal capacity on the decantation system, and the working costs are also considerably lower.

After leaving the slimes-plant, the pulp is delivered to three-throw pumps T which charge the filter-presses X.

Quantity treated	3,255 tons.
Average value of slimes before treatment .	1·99 dwt.
Average value of residue	0·34 ,,
Theoretical extraction	82·91 per cent.
Actual extraction	80·41 ,, ,,
Total gold won	262·1 ounces.
Value of gold won	£1,113 15 2
Total working costs	£332 16 4
Total profit for the month	£780 18 10
Profit per ton on treatment of 1·99 dwt. slimes	4*s.* 9·55*d.*

Filter-Press.—The filter-press arrangement is shown to a larger scale in Figs. 48, Plate 6. The pulp is delivered to the press by means of a pump, either directly or through a "steady head" tank or similar device. When the charging of the press is effected by means of a pump directly, a large air-vessel is fitted on the charging-pipe to minimize the pulsations, which even with a multiphase pump may become dangerous. A gauge indicates the limiting pressure which should be reached when the press is full. This varies, according to circumstances, between 50 lbs. and 100 lbs. per square inch. There are several elaborations of this simple form of press, the variations consisting in the number and construction of the plates and cells, and of the inlet- and outlet-passages and ports.

In the modern Dehne press there are two kinds of filter-plates, termed the "high"- and "low"-pressure plates, the series consisting of alternating sets of the two filter-plates, with a chamber between. The ports are arranged so as to provide for a reversal of flow in order to wash the filter-cloths or to pass a water or re-agent wash through the solid material retained in the chambers. An orifice, sometimes fitted with a cock and sometimes left continuously open, is also provided at a bottom corner of each filter-plate. By these means the rupture of a filter-cloth or any irregularity in the working of any member of the series can be immediately detected and that member cut out by closing the corresponding orifice.

In the filter-press plant illustrated in Figs. 48, Plate 6, A is the slimes inlet-pipe and valve, B the outlet-cocks for the filtered solution, C the inlet-pipe and valve for the water or solution-wash, D the outlet, and E an inlet-valve for compressed air. The press proper is supported by cast-iron standards and stanchions R on the masonry-piers shown. F and F_1 are respectively the fixed and movable cross-heads. K K are the chambers or cells, and K_1 K_2 the two kinds of filter-plates. L is the launder which receives the effluent filtrate from the cocks B, and M is the main launder which collects the filtrate from the launders L. Q Q are the tension-bars,

which also support the filter-plates and cells. T is a three-throw slimes-pump fitted with an air-vessel T_1 and a relief-valve T_2. S is a water or solution wash-pump. G is a drain-cock on the feed-channel. P is the hydraulic cylinder, and N the ram by means of which the plates and cells are held together during the charging operation. H is the pressure-pipe from the accumulator U, and J the return-water pipe to the hydraulic pressure-pump V. W is an air-cock in the end filter-plate.

Referring again to Figs. 46, Plate 6, the sumps P are steady-head and filter-tanks for controlling the solution from the slimes-plant to the extractor-boxes R. These extractor- or precipitation-boxes are made of steel, each box being 16 feet 7¾ inches in length by 4 feet in width, divided into seven compartments containing wooden trays with wrought-iron handles. The solution, after flowing through the extractor-boxes R, is delivered to the sump S. The sulphuric acid treatment-vats U are for the purpose of dissolving out excess zinc in the gold slimes.

Filtrate.—The effluent filtrate is collected and led away in suitable troughs to its destination, and the solid matter, when the press is full, is taken out in the form of cakes, to be discharged to the dump in the case of residues or passed to the calcining furnace in the case of gold-bearing zinc slimes. The cost of filter-pressing on the Rand is not expected to exceed 1*s.* per ton of slimes pressed, as it is not proposed either to treat or wash in the press, but merely to express the gold solution in one operation.

Sulphuric Acid treatment-tanks.—These wooden tanks are used, in conjunction with a filter-press, for the clean-up of the zinc-gold slimes. The slimy sediment from the zinc extractor-boxes is placed in two primary tanks, which are raised on the wooden platform at a convenient height above the large settling-tank. The cyanide solution remaining in the slimes is pumped out and the zinc is dissolved off with sulphuric acid. A counterbalanced hood and chimney, capable of being raised and lowered as required, are arranged over each tank to conduct away any fumes. V are small filter-presses for use in the cyanide clean-up for the separation of the zinc-slimes from the solutions. W are lathes for ribboning zinc for use in the extractor-boxes. The centrifugal pumps T are for the purpose of pumping the cyanide and other wash-solutions.

An arrangement for distributing the leached gold-solution to the extractor-boxes is shown in Figs. 49, Plate 6. A number of pipes *a*, leading from the treatment-tanks, and each fitted with a cock *b*, feed into a similar number of troughs *c*. Each trough is capable of sliding horizontally and has a discharge-pipe *d* in the bottom at one

end. They are so arranged over a series of channels *e* that any discharge-pipe can be fed into any one channel independently. These channels lead through delivery-pipes *f* into tanks, from the top of which pipes lead directly to the extractor-boxes. The tanks catch any sand that may have perforated the filter, and also maintain a steady flow of solution through the boxes.

Extractor-House.—The extractor-house is the department of the cyanide treatment-plant in which all the operations in connection with the precipitation of gold from cyanide solutions, the treatment of zinc-gold slimes by sulphuric acid, the preparation of ribbon-zinc for the extractor-boxes, the calcining and smelting of the gold, are carried out. The general interior arrangements are shown in Figs. 46, Plate 6. Fig. 50, Plate 6, is a diagram showing the flow of solution through the various portions of a plant recently completed to the same general scheme as that shown in Figs. 46, Plate 6. The distribution in this plant, of which the following are details, is based on a mill-duty of 20,000 tons per month, or say, 650 tons per day:—

	Tons.	
A is the 120-stamp mill.		
Tailings-wheel B receives	650	ore from stamps per 24 hours.
" " "	6,000	solution do. do.
" " delivers to spitzlutte C	215	slime from tube-mills D do.
" " " " "	1,290	solution do. do.
Spitzlutte C deliver	650	fine sand and slime to spitzkasten E.
" "	6,500	solution do. do.
" "	215	coarse sand to tube-mills D.
" "	1,290	solution do. do.
Spitzkasten E deliver.	240	fine sand to leaching-vats F.
" "	24	solution do. do.
" "	195	slimes from stamps to primary slimes settler G.
" "	5,186	solution do. do.
" "	215	slimes from tube-mills D to primary slimes-settler G.
" "	1,290	solution do. do.
Leaching-vats F receive	240	fine sand from spitzkasten E.
" "	24	solution do. do.
" "	[1] 120	strong wash from sump M.
" "	24	wash-water from mine-supply.
" and deliver . . .	240	fine sand to dump.
" "	24	wash-water do.
" "	144	solution to extractor-boxes L_1.
Tube-mills D receive	215	coarse sand from spitzkasten E.
" "	1,290	solution do. do.
" and deliver . . .	215	slime to tailing-wheel B.
" "	1,290	solution do. do.

[1] All the other cyanide washes are made up from unprecipitated solution from filter-presses.

	Tons.
Primary slimes-settlers G receive . .	215 tube-mill slimes from spitzkasten E and settler.
,, ,, ,, ...	195 battery A do. do.
,, ,, ,, ...	6,475 solution with above do.
,, ,, and deliver .	410 slime to slime-vats a and a_1.
,, ,, ,, .	956 solution do. do.
,, ,, ,, .	5,520 solution to return-water tank H.
Slime-vats a and a_1 receive	410 slime.
,, ,, ...	956 solution.
,, and deliver . .	410 slime to vats $b\,b_1$, $c\,c_1$, $d\,d_1$.
,, ,, . . .	761 solution do. do.
,, ,, . . .	195 solution to return-water tanks.
Slime-vats $b\,b_1$, $c\,c_1$, $d\,d_1$, each receive .	410 slime.
,, ,, ,, .	761 solution.
,, ,, ,, .	195 cyanide solution from sump M.
,, ,, and deliver .	410 slime.
,, ,, ,, .	761 solution.
,, ,, ,, .	195 solution to extractor-boxes L_1.
Filter-presses N receive	410 slime.
,, ,, ...	761 solution.
,, ,, ...	90 wash-water from mine-supply.
,, and deliver . . .	410 slime to dump.
,, ,, ...	90 water-wash to dump.
,, ,, ...	761 solution to extractor-boxes L_1 (partly *viâ* leaching-tanks).
Extractor-boxes L_1 receive	144 solution from leaching-vats.
,, ,, ,, ...	585 ,, ,, slimes vats overflow.
,, ,, ,, ...	761 filter-presses.
Sumps M receive	1,490 solution as above.
,, and deliver	120 solution to leaching-vats F.
,, ,, ...	585 ,, slimes-vats a and a_1.
,, ,, ...	785 ,, return-water tanks H.
Return-water tanks H receive . . .	5,520 solution from primary slimes-settler.
,, ,, ,, . . .	195 solution from slimes-vats a and a_1.
,, ,, ,, . . .	785 precipitate solution from sumps.
,, ,, and deliver .	6,500 to battery feed-tanks O.

A feature of this treatment is that cyanide solution is in circulation through the entire plant in lieu of water as formerly.

Proposed Plant in substitution for ordinary Stamp-Milling, Sands- and Slimes-Treatment Plants.—The Author has made many references in this Paper to his conviction that it is possible to design a more suitable plant for treating Witwatersrand ores than that now generally in vogue, and one in which the fundamental portions of the ordinary plant may be entirely dispensed with. The objections that may be raised to stamp-mills, and to the ordinary sands-treatment

plants, have been touched upon. Briefly, the objections raised have reference to the capital cost and the working charges, with the additional disadvantage that in neither the stamp-mill nor the sands-treatment plant can the whole of the gold be subjected to treatment, because of the fact that it has not been liberated from its quartzitic gangue. During the past few years the Author, assisted by his brother, Mr. H. S. Denny, has devoted considerable attention to the question of fine grinding, and the possibility of extracting the liberated gold by means of a process which would eliminate many of the objections inherent in the sands-treatment and slimes-treatment plants now mainly in use. It was demonstrated beyond doubt by a plant which the Author erected on one of the leading mines on these fields, that the gold in finely-comminuted ore was readily amenable to the action of cyanide solutions, and as ore in a condition of great fineness could readily be transported by water from point to point under gravity-head, it was quite clear that a method of treatment might be devised in which the handling-charges could be reduced to a minimum. The Author has had wide experience in the fine grinding of ores in other gold-fields, and as soon as the original experiments in connection with fine grinding and gold-saving were confirmed by the success of a working plant on a large scale, he turned his attention to the question of stage-breaking and stage-grinding. A diagrammatic arrangement of the plant now proposed by the Author is shown in Figs. 51, Plate 6. The first-stage breaker A is a machine of the gyratory type, of large output, and designed to deliver ore of 4-inch to 5-inch ring-gauge into the revolving trommel A_1. This trommel performs the ordinary duty of delivering any pieces of ore over gauge to an elevator-boot A_3 from which the ore is elevated and returned for further reduction. The ore passing through the perforations of A_1 is deposited in an ore-bin A_2. This ore-bin discharges into the second-stage breaker B, of the Blake type, in which the ore is reduced to 1½-inch to 2-inch ring-gauge, and is delivered into the revolving trommel B_1; the separation of the over-sized rock is made in B_1, this material being elevated back to B by means of the elevator B_3. The ore-bin B_2 feeds the third-stage fine-breaker C. This breaker is of the roll-jaw type, and is so designed that it will continuously deliver material of nearly equal size, the design being to get a delivery from it of ore-particles not exceeding ½-inch ring-gauge, and preferably smaller. The same sizing and elevation as before is performed by the trommel C_1 and the elevator C_3. The ore-bin C_2 delivers particles not exceeding ½-inch ring-gauge to the feeder D, which regulates the supply into an edge grinding-pan E. This is a machine of the Chilian mill type, but so modified as to give an out-

put of between 100 tons and 150 tons of ore per day through a 20-mesh screen. Amalgamation of the heavier particles of gold will be done inside this mill. The discharge from the mill will pass on to a shaking-table F which is shown to a larger scale in Figs. 29, Plate 5, where further amalgamation will take place, the discharge from F entering the grinding-pan G. In this pan a certain amount of amalgamation of gold particles will be secured. The pulp flowing from G will be passed over another shaking-table F_1, whence the whole of the pulp will flow into the conical separating-vat H, shown also in Figs. 33, Plate 5. It will be seen that the system aims at a high percentage of gold extraction. The Author thinks it not improbable that 80 per cent. of the total gold saved will be obtained from amalgamation. The various portions of the reduction and treatment scheme as diagrammatically shown in Figs. 51, Plate 6, are not proportionate, the idea being merely to illustrate the principle. In the separating-vat H, a concentration of the solids is effected, and the overflow, which is cyanide solution, will be taken by a pipe J, directly through a filter-tank K to the extractor-boxes S. The solution carrying the pulp is in all cases made up to a certain strength of cyanide solution, and necessarily, as there is violent agitation in the first- and second-stage grinding-mills, all the fine gold which has escaped amalgamation will have been dissolved by the time it reaches the conical separator H. Should there be still any undissolved gold, however, it has ample time in contact with the cyanide solution before its discharge from the bottom of the vat. It will be realized that the uprising cleared solution from the vat H is gold-carrying, and could therefore be sent to the precipitating-boxes. The concentrated pulp in the tank H is continuously and automatically discharged to the slimes-pump L, which fills the filter-press M, shown to a larger scale in Figs. 48, Plate 6, and the operation of filter-pressing completes the cycle. The expressed solutions from the filter-press M run through the launder N into the clarifying-tank K for delivery to the extractor-boxes S. P is a pressure-pump pumping against an accumulator R. U is a solution-pump pumping from the storage-sump T through a pipe V to the Chilian mill E. O is a tram-line on which the residues are trucked to the dump.

The new combination of reduction- and treatment-plant here proposed, whilst differing radically from the combination now used on these fields, is essentially the same in its general principles, namely, rock-breaking, first-stage fine breaking (at present done by stamp-mills), second-stage reduction (at present done by tube-mills), amalgamation of the coarser particles of gold, and subsequent treatment of the sands and slimes by cyanide solution. The special

objects of the new combination are, however, simplification of the methods now employed, a more concentrated plant, less capital expenditure, and lower working-charges. The combination as arranged dispenses with three important operations of the usual milling-equipment, namely (1) stamps, (2) sands-treatment, (3) slimes-treatment plant. The principles underlying the design are founded upon the experience that the reduction of ores can be at least as cheaply accomplished by rock-breakers and mechanical grinders as in stamp-mills; that the capital cost to secure the same output would certainly be less in the proposed plant than in the stamp-mill, sands- and slimes-treatment plants; that the gold in the Rand ores is readily dissolved in weak cyanide solutions if the ore is so comminuted as to render it easily accessible to the solutions; that a finely-ground ore, being readily transported by water, reduces the cost of handling; that treatment of the ore whilst in passage from one section of the plant to the next necessarily reduces the storage- and treatment-capacity required; and that a continuous and practically automatic system of handling and concurrent treatment must prove superior to the existing methods.

Referring to the design proposed, it will be seen that there is no flouting of the principles which experience has dictated as being best suited to the Rand ores. In the first part of the scheme there is first, preliminary breaking; second, intermediate breaking; and third, fine breaking. This sequence of ore-reduction in its entirety has already been successfully put in operation by the Author on three large mines on these fields. Here, therefore, is nothing new or in the nature of an experiment. In the second part of the scheme there are, first, Chilian mills and amalgamating-plates; and second, grinding-pans and amalgamating-plates. The Chilian mill, as is well known, is one of the oldest forms of ore-grinding machinery, and has been used extensively in all mining regions. Its place, perhaps, in the reduction and treatment system has not been exactly that assigned in the present design, inasmuch as it is here proposed to substitute it for the stamp-mill in the reduction of the ore-particles from, say, $\frac{3}{8}$-inch to $\frac{1}{2}$-inch ring-gauge down to 20-mesh screen. The machine consists of three edge-runners which are heavily loaded in order to give large crushing-capacity. The mil is, however, essentially of the Chilian mill type, and its performances therefore are well known and its possibilities of output and cost can be fairly accurately gauged. Mills of this class are now built having a capacity on hard quartzite rock of 125 tons per day with an absorption of 50 horse-power. The runners of this mill have diameters up to 6 feet and widths of face up to 12 inches, whilst

their effective crushing-weight is as high as 50,000 lbs. The grinding-pan is a machine which is in use on all goldfields, either purely as a grinding medium or as a combination grinder and amalgamator. It has been run in West Australian fields in competition with the tube-mill, and the opinion expressed by competent and practical metallurgists on those fields is that it is in many essential features superior to tube-mills, and is likely in the future to supersede them entirely. In neither of these machines, therefore, which make up the second-stage portion of the plant, can anything in the nature of an experiment be urged. The remaining portion of the plant is in evidence as a successful gold-saver on these fields, although not exactly in the combination here proposed. It will be seen, on reference to Figs. 46, Plate 6, that the plant is essentially the same as that actually in operation on some mines under the Author's supervision, with the exception that in this case the slimes-plant proper is eliminated, the reason for this being that owing to the fine state of division of the ore, and to the fact that it is ground and agitated in presence of cyanide solution, there is every reason to believe, from experience already gained with similar plant, that all the gold will be dissolved by the time it reaches the filter-press plant, obviating therefore the necessity of putting in, as had been done in former designs, the intermediate slimes-plant. Assuming that the gold were not all dissolved by the time it reached the conical vat shown, it would only be necessary, in order to ensure the solution of all the gold, to increase the number of these vats, thus giving a longer time of contact.

The question of capital outlay in connection with the two plants is one which requires the greatest consideration. On the one hand the cost of the erection of stamp-mills is well known, and on the other the cost of the erection of this plant could only be a matter of estimate. It may be taken that to erect a stamp-milling plant complete with cyanide- and slimes-plant, and the necessary power in connection therewith, would cost on these fields £1,000 to £1,200 per stamp erected. Without committing himself to any figure for the new plant, the Author is perfectly satisfied that it can be erected, for equivalent output, at much less cost.

The Paper is accompanied by thirty-six drawings, from which Plates 5 and 6, and the Figures in the text, have been prepared.

(*Paper No. 3606.*)

"A Sterilized Water-Supply at Leavesden Asylum."

By WILLIAM THOMAS HATCH, M. Inst. C.E.

THE Leavesden Asylum, in Hertfordshire, is situated 3 miles north of Watford, at an elevation of 350 feet above sea-level. In 1899 an exceptionally severe outbreak of diarrhœa was noticed amongst the patients, with a correspondingly high death-rate. On investigation it was found that similar but less severe manifestations had been observed in previous years; and that the death-rate in this Asylum had been much higher than that in sister-institutions elsewhere under the same Board.

Articles of diet were examined, and sanitary details tested, but were found to be fairly satisfactory. The sewage is treated on a farm having a total area of 27 acres, but a large portion of this area is put out of use for lengthened periods.

The water-supply was next examined, and, although drawn from a well 225 feet in depth, in the chalk, was found upon bacteriological examination to be contaminated with surface-organisms to a sufficient extent to justify the conclusion that this was the source of the outbreak. The well-water was therefore shut off from the drinking-supplies and a limited service was laid on from an outside source, which was not, however, of sufficient volume to supply the needs of the institution, these requiring 80,000 to 100,000 gallons per day. Various alternatives were considered, the first being that of arranging for supplies from an outside source; and as the Asylum estate comprised portions of districts covered by two entirely distinct water companies, competitive terms were obtained which were presumably the lowest procurable, but nevertheless were not sufficiently attractive to induce the Metropolitan Asylums Board to adopt this method of getting over the difficulty. The next alternative was water-softening by the lime-process; it was suggested that the objectionable organisms would be thrown down with the chalk during the process of "softening," and would thus

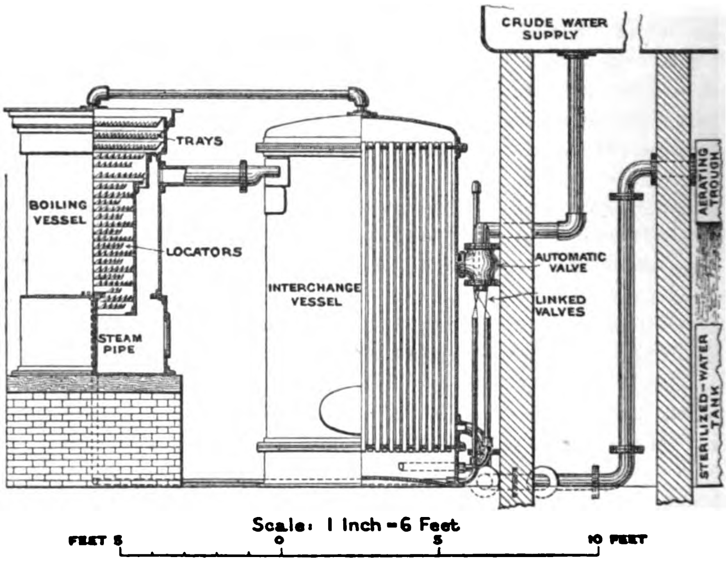
be eliminated. As it was not absolutely certain, however, that this would be the case, and as the health and lives of about 2,500 persons depended upon the result, further consideration of this method was discarded. The next scheme considered was the adaptation of some form of sterilization, two forms being discussed, namely, chemical and mechanical; the first was ruled out of court on account of the difficulty of finding a suitable agent which would destroy the injurious organisms and yet be innocuous to human beings, whilst the mechanical method involved some risk, as it could not be ascertained that any attempt had been made to treat by this means so large a volume of water as 9,000 gallons per hour. Here the question of expense arose, and inquiries in various quarters resulted in offers to install a plant which would sterilize the water at costs for fuel ranging between 1¾*d.* and 1*s.* per 1,000 gallons treated, the treatment consisting in each case of boiling and subsequent aeration. It was thought that if the lowest cost could be adhered to, namely, that quoted by the Lawrence Patent Water-Softening and Sterilizing Company, Limited, who supplied the apparatus described in this Paper, the existing supply, with its accompanying machinery, might be utilized. Moreover, the water would be not only sterilized but also softened—an important consideration, having regard to the fact that the well-water, being drawn from "the chalk," was exceptionally hard—and the whole cost of pumping, sterilizing and softening would not amount to one-half that of either of the outside supplies.

The questions to be discussed included the important one of the final temperature of the water when leaving the apparatus, as it could not be allowed to escape at boiling-point and cool down slowly to the desired temperature; it was therefore decided to arrange that the difference in temperature between the incoming and outgoing waters should not exceed 20° F., and the temporary hardness should be reduced from 19° to 9° on the Clark scale. A small apparatus, having a capacity of about 30 gallons per hour, was first tried, and the results obtained were very satisfactory; the temperatures and softening were well within the limits laid down, and the water was pronounced by the Asylum Board's bacteriologist to be absolutely sterile. The larger plant, capable of sterilizing 9,000 gallons per hour, was then considered, and temporary arrangements were made by installing first a plant capable of sterilizing 5,500 gallons per hour. This plant is referred to as No. 7 in the Table given in the Appendix. From the data obtained from its working, the plant which has been finally installed was constructed; it has been in constant use for 12 months, giving very satisfactory

results, at a working-cost certainly not exceeding $1\frac{1}{2}d.$ per 1,000 gallons for fuel. The cost for fuel can be easily checked, as asylum-work is very regular, and the coal-bill for any 12 months is readily comparable with that for previous years.

The advantages of the boiler-type of sterilizer lie in the fact that no filtering-material is used, so that the danger of trouble arising from this portion of a plant being left unchanged or uncleaned is entirely avoided; and in the ease with which the various "locator"-plates can be removed and the adhering scale released. The

Fig. 1.

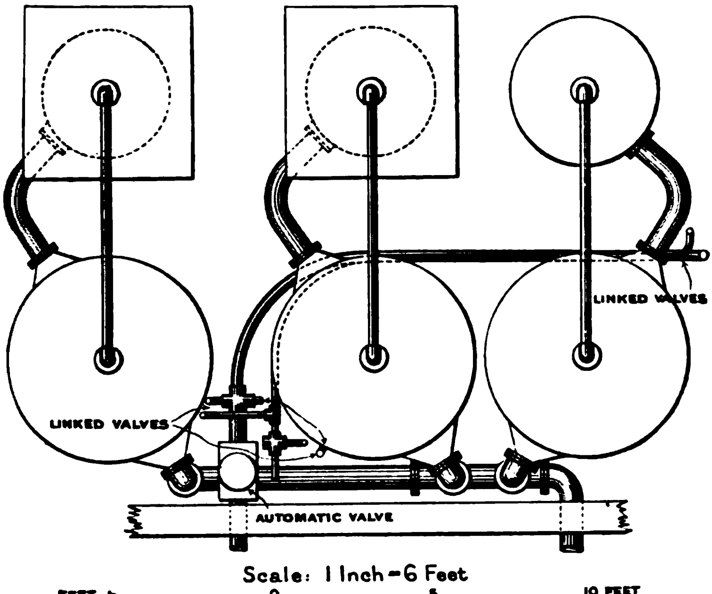


SECTIONAL ELEVATION OF ONE OF THE THREE UNITS OF THE LEAVESDEN ASYLUM PLANT.

apparatus consists of three independent units, each dealing with 3,000 gallons of water per hour, the water being boiled by the injection of live steam only. Each unit, *Fig. 1*, consists of a heat-interchange vessel, similar in form to a surface-condenser, 5 feet 10 inches in internal diameter by 9 feet 6 inches in height between the tube-plates, and containing 580 solid-drawn copper tubes, 2 inches in diameter, expanded into brass tube-plates; and a boiling-vessel of mild steel plate, the upper part holding perforated trays on which a considerable portion of the scale is deposited, and the lower part forming a mud-chamber. Two of the boiling-vessels at Leavesden

have square tops and bottoms, the central part being cylindrical; the third vessel is cylindrical throughout, *Fig. 2.* In the centre of the boiling-vessel a galvanized inner cylinder is fixed, as shown in *Fig. 1*, containing the "locator"-plates, upon which the carbonates are deposited in solid form. The action of the apparatus is as follows:—The water-supply, taken from a large overhead tank, first passes through an automatic valve controlled by a steam-piston, so regulated that should the steam-pressure fall, from any cause, the whole

Fig. 2.



PLAN OF THE LEAVESDEN ASYLUM PLANT.

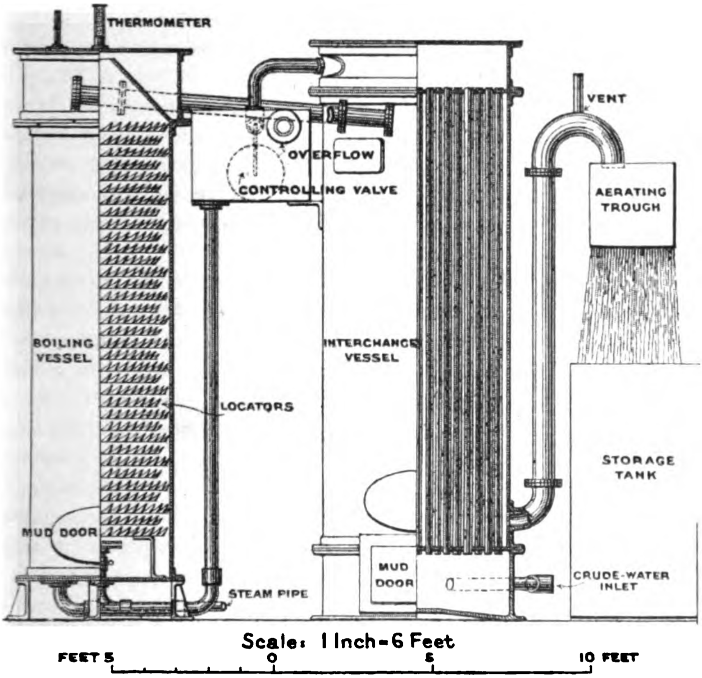
water-supply is immediately shut off; the water is then led into the bottom boxes of the interchange-vessels, and, slowly rising through the tubes, attains a temperature of about 190° F. by taking up the heat from the return-water outside the tubes. It then passes over from the top box through the cover of the boiling-vessel, falling first over the trays, which are above the water-level. These trays are of mild steel, and are bolted together in groups for easy removal, the edges being "finned" in order to break up the flow of water. Large trays having a hole in the centre alternate with

smaller trays having no hole, thus dividing the ebullition-cylinder into a number of chambers and presenting as large a surface as possible for the collection of deposit from the water while it is boiling. Steam is taken in through the bottom of the boiling-vessels and discharges between a pair of flanges in a horizontal direction, rising upwards against the downward flow of water and escaping to atmosphere, if not condensed, through vent-pipes in the covers of the boiling-vessels. The boiled water, having reached the bottom of the ebullition-chamber, rises in the annular space between the two cylinders and passes out by the return-pipe into the heat-interchange vessel just below the top tube-plate. Descending slowly outside the copper tubes, it parts with its heat and leaves by an outlet-connection just above the bottom tube-plate on the opposite side, *Fig. 1.* The three outlet-pipes are taken to one collecting-pipe, which is carried to the proper level to keep the interchange-vessels full of water, and there discharges into a teakwood aerating-trough in the open air, having a copper bottom perforated with fine holes, the size and number of which are so adjusted as to give the "critical head" to ensure fine streams descending individually, without mingling, into the tank below; this results in a most satisfactory re-aeration of the sterilized water. The water is then pumped up into the main storage-tank in the water-tower, whence it flows by gravity to all parts of the Asylum.

The form in which the plant is now made is shown in *Fig. 3*, and is in many respects a distinct advance upon that shown in *Fig. 1.* The automatic valve, with its steam-piston, is dispensed with, and the water is taken directly into the bottom box in two places, to ensure better distribution to the tubes. The internal diameter of the heat-interchange vessel remains the same, but the distance between the tube-plates is 10 feet instead of 9 feet 6 inches, and if 2-inch tubes are adopted 600 tubes are used. A 2-inch plug is provided in the centre of the top tube-plate for the insertion of a hose-pipe to wash away any soft scale that may form in course of time on the outside of the tubes. The top box is made with a flat top, and the outlet is taken from the side opposite to the two inlets, instead of from the centre, the object being to secure the best possible distribution between the tubes. The water flows from the top box into a large ball-valve tank, from which it is taken to the bottom of the boiling-vessel; this tank is provided with an overflow-pipe. The boiling-vessel consists of a cylinder, 10 feet in height by 2 feet 11 inches in internal diameter, and is filled with "locator"-plates, the area of the depositing surface being about double that provided by the apparatus shown in *Fig. 1.*

It is surmounted by a discharge-box of somewhat larger diameter and a movable cone having an opening at the top. The water-level is normally 4 inches below the top of this cone. Until ebullition is attained in the boiling-vessel no water can possibly pass over, and any leakage through the ball-valve would be taken away through the overflow-pipe in the valve-tank, which is at a lower level than the top of the cone. The water-supply valve may therefore always be

Fig. 3.



LAWRENCE AUTOMATIC STEAM STERILIZER AND SOFTENER.

left open, and the apparatus worked solely by the steam-valve; the amount of water passing through will be directly proportional to the amount of steam used, the process of ebullition being quite sufficient to raise the water over the top of the cone, thus ensuring that every drop of water passing through the apparatus shall have been actually boiled, and therefore sterilized. A vent-pipe to atmosphere is provided in the cover of the boiling-vessel as in the apparatus previously described.

When working at the rate of 3,000 gallons per hour the time taken by each particle of water to pass through the boiling-vessel is 10 minutes, the temperature varying between 212° and 225° F. As soon as the water is discharged over the top of the cone, owing to the difference in statical head between the column of water from the valve-tank to the bottom of the boiling-vessel, and the column of mixed water and steam in the boiling-vessel, the water returns to the heat-interchange vessel by two pipes connecting with that vessel at points 120° from the outlet, and from each other. As the whole of the water in this apparatus must boil for 10 minutes before leaving the ebullition-chamber, any deposit on the outside of the tubes in the interchange-vessel is found to be very slight. The extreme simplicity of this design, both in working and in construction, is obvious. For use in tropical countries as a sterilizer only, where the water is very soft, the sterilizing-chamber might be made quite small and fixed on the top of the heat-interchange vessel, reducing the actual ground-space required, exclusive of the storage-tank, to about 7 feet by 6 feet 6 inches.

Bacteriological test.—As it was absolutely essential that no contact should take place between the incoming and the outgoing water, bacteriological tests were made by putting into the water a special organism not normally present in it. If this organism could be demonstrated to be present in the effluent, it might be concluded that some portion of the supply had escaped the process of sterilization. The organism selected was *Bacillus Prodigiosus*, which produces a brilliant red pigment when grown on ordinary culture-media, and thus enables it to be picked out at once from any other organisms which may be present. In carrying out this experiment it was necessary to ascertain how long the water took to pass through the apparatus, and for this purpose a solution of common starch was used; its presence at the outflow was easily detected by its giving a dark blue colour when tested with a solution of iodine. The apparatus was "fed" with the starch-solution for 10 minutes before the test-organism was introduced, the full quantity of water (9,000 gallons per hour) being passed through, as in ordinary working. The total capacity of the various vessels composing the apparatus is about 6,000 gallons, and the starch-experiment showed that the time required for any particular body of water to undergo the complete cycle of operations was about 45 minutes, the starch being recognized in the effluent after that period. As the *Prodigiosus* emulsion was added immediately after stopping the introduction of the starch, it was an easy matter to decide when to commence taking samples for

the bacteriological tests. Thirty-two samples were taken in all, extending over the whole period during which traces of starch could be detected in the effluent, and in no instance was there found any sign of *Prodigiosus*.

Coal-consumption.—A test was made to ascertain the cost of fuel necessary for sterilizing-purposes, but this could not be accurately carried out owing to the necessity of using one of the four Lancashire boilers installed at the Asylum, which was much too large for the purpose and was situated some 200 feet away from the sterilizer. The specially long steam-main required to isolate the plant from the rest of the institution accounted for very large losses due to radiation, whilst under ordinary conditions the supply of steam is taken from a main supplying the general requirements of the Asylum and passing within 20 feet of the sterilizer. The cost of fuel for this test was 2¼*d.* per 1,000 gallons, when sterilizing 9,000 gallons per hour, and with coal costing 17*s.* 1*d.* per ton delivered at the Asylum, but returns extending over 12 months under ordinary working conditions show that the cost does not exceed 1½*d.* per 1,000 gallons.

Temperatures.—The monthly records of the average temperatures of the incoming and outgoing water are given in the following Table,

Date.	Average Temperature of Incoming Water during Month.	Average Temperature of Outgoing or Sterilized Water during Month.	Difference in Temperature between Incoming and Outgoing Water.
1904	°F.	°F.	°F.
October	53	76	23
November	53	75	22
December	52	74	22
1905			
January	52	74	22
February	52	73	21
March	52	72	20
April	52	71	19
May	52	73	21
June	53	74	21
July	54	74	20
August	54	75	21
September	54	75	21

from which it will be seen that the smallest differences in temperature

were obtained, not in the winter months, when the losses from radiation might be expected to be greatest, but in the summer months, and when the various cooling-tubes of the apparatus were incrusted with an accumulation of carbonates to a thickness of $\frac{1}{4}$ inch at the upper ends of the copper tubes in the heat-interchange vessels, thus showing that under certain conditions the accumulation of scale, even to an extensive degree, does not materially affect the transmission of heat through metal surfaces protected by such incrustation.

Experiments made in connection with the design of the apparatus.—Experiments were made to determine the following points in connection with the design of this plant:—

(*a*) The size of tubes which would give the best results.

(*b*) Whether any advantage would accrue from the use of a tube bent in the form of a spiral.

(*c*) Whether by disturbance of the water outside the tubes in the interchange-vessel a more rapid transference of heat could be brought about.

(*d*) Whether the use of baffle-plates to prevent local vertical displacement of the water was advantageous.

(*e*) The critical speed for the water passing through the interchange-vessel.

(*f*) The effect of increasing the space between the tubes.

(*g*) The effect of varying the area of the surface presented by the interchange-vessel.

In order to investigate these points, experiments were made with the following apparatus:—

(1) An ordinary 20–25-gallon Lawrence plant.

(2) A tubular heat-interchange vessel, $4\frac{3}{4}$ inches in diameter, containing nineteen tubes, each $\frac{3}{4}$ inch in diameter, $\frac{1}{30}$ inch in thickness and 2 feet in length between the tube-plates, the tubes being so arranged as to facilitate as much as possible the interchange of heat.

(3) The same arrangement as in (2) but with baffle-plates introduced so as to cause the water to circulate backwards and forwards between the tubes in its descent through the vessel.

(4) An annular vessel, 10 inches in external diameter and $16\frac{1}{4}$ inches in height, containing a spiral formed from a copper tube 38 feet in length, $\frac{3}{4}$ inch in diameter and $\frac{1}{30}$ inch in thickness.

(The area of the heat-interchange surface in all these apparatus was as nearly as possible identical, and in the case of (2) and (3) the diameter of the containing vessel was so proportioned as to give nearly the same volume of water inside and outside the tubes, in

order to make the velocity of the water ascending through the tubes the same as that of the water descending outside them.)

(5) A tubular heat-interchange vessel, 7½ inches in diameter, containing six tubes, $\frac{1}{16}$ inch in thickness, 2 inches in diameter and 22⅛ inches in length; these tubes were flattened throughout most of their length to an elliptical form, the minor axis being ⅞ inch. The capacity inside and outside the tubes was made double that of (2) and (3) so as to double the time taken for a given volume of water to pass through the apparatus.

(6) The same apparatus as in (2), the number of tubes being reduced from nineteen to ten, thus reducing the heat-interchange surface from 7·5 square feet to 4 square feet, and increasing the spacing of the tubes from 1½ inch to 2¼ inches.

(7) Full-size apparatus capable of dealing with 5,540 gallons per hour.

The results of the experiments are shown in tabular form in the Appendix, but before proceeding to draw any conclusions from them it may be well to consider the conditions which control the interchange of heat between two sides of a plate kept at a constant difference of temperature. The rate of interchange per unit of area depends (1) on the conductivity of the metal; and (2) on the difference of temperature between the two sides of the plate, being proportional to that difference. Column G in the Appendix gives the number of heat-units given up per square foot of interchange-surface by the sterilized water, in cooling, to the unsterilized water passing through the heat-interchange vessel to the boiling-vessel. The number is obtained by multiplying the number of gallons passing through per hour (Column B) by the rise of temperature (difference of Columns C and D), and dividing by the area of the interchange-surface, and is expressed in British Thermal Units. Column H gives the heat lost by the sterilized water in cooling, being the discharge (Column B) multiplied by the difference of the temperatures given in Columns E and F and divided by the area of the interchange-surface.

The conclusions which may be drawn from the results of the experiments are:—

(*a*) The best results have been obtained with flattened tubes 2 inches in diameter (No. 5).

(*b*) No advantage is gained by adopting a spiral instead of a straight tube (No. 4).

(*c*) The water when cooling down is much better left undisturbed. (The results of the experiment from which this conclusion is drawn are not shown in the Table.)

(*d*) The use of baffle-plates in the small apparatus appeared to produce no beneficial effect (compare Nos. 3 and 2).

(*e*) The effect of varying the rate of flow (Column B) is very much less marked than might have been expected, comparing (3) and (5).

(*f*) The effect of increasing the spacing of the tubes, within certain limits, did not decrease the efficiency (compare Nos. 6 and 2).

(*g*) In No. 6 the interchange surface was 4 square feet; in No. 2 it was 7·52 square feet; and the amount of heat interchanged is almost proportional to the surface.

The mechanical difficulties attending the use of elliptical tubes led to the final adoption of a round tube of 2 inches diameter for the Leavesden apparatus; this probably accounts for the fact that the results obtained with the actual apparatus installed (No. 8) are not quite so good as those obtained with the experimental plant (No. 5).

With regard to the rate of interchange of heat through the walls of the tubes, no conclusions can be drawn as to the relative efficiency of tubes of different materials, as only copper tubes were used in the experiments. As to the thickness of the tube, in (1) and (7) the metal was $\frac{1}{50}$ inch in thickness, in (2), (3), (4) and (6) it was $\frac{1}{30}$ inch, and in (5) it was $\frac{1}{16}$ inch, but the actual results obtained show that the thickness of the metal can have very little effect. The explanation of this lies probably in the fact that the mean path for the transference of heat from the water, through the plate, to the water, lies for a considerable distance through water, the conductivity of which is low, and only for a very short distance through copper, the conductivity of which is high. The total resistance to the flow of heat would therefore be practically that offered by the water, the resistance offered by the copper being negligible. For the same reason it is probable that other metals, of less conductivity, might be used for the tubes without materially affecting the results, and this contention is supported by the fact that, as already pointed out, a considerable quantity of scale may accumulate on the tubes themselves without materially diminishing the efficiency. The interchange of heat is shown by the results to be proportional to the difference between the mean temperatures of the water inside and outside the tube.

In conclusion, the Author is of opinion that the process of sterilizing water by the application of heat is of immense importance where certainty of action, simplicity of construction, and the use of unskilled labour are necessities.

The particulars given in this Paper refer to steam-heated apparatus only, but there is no reason why the heat should not be applied directly by means of a Bunsen burner, oil-lamp or coal-fire; indeed, portable plants heated by one or other of these means have been already tried by the War Office authorities.

The Author desires to express his indebtedness to Mr. W. J. E. Binnie, M. Inst. C.E., for valuable aid in connection with the apparatus, to Dr. Cartwright Wood, for the results of the bacteriological tests, and to Mr. G. W. Westrope, of the Lawrence Sterilizing Company, Limited, for the very ingenious suggestion of using the cone at the top of the boiling-vessel, instead of the automatic control-valve, to cut off the supply of unsterilized water should actual boiling not take place.

The Paper is accompanied by three sun-prints, from which the Figures in the text have been prepared.

[APPENDIX,

APPEN

Results of Tests of Water-

No.	Nature of Apparatus.	Discharge in Gallons per Hour.	Temperature of Cold Unsterilized Water.	Temperature of Hot Unsterilized Water.
	Column A.	Column B.	Column C.	Column D.
		Gallons.	°F.	°F.
1	Lawrence 20–25 gallon (nominal) apparatus, copper about $\frac{1}{50}$ inch in thickness; interchange surface, 7·5 square feet . . .	6·4 16·8	37 45·5	183·5 169
2	Tubular interchange-vessel, nineteen ¾-inch tubes, $\frac{1}{50}$ inch in thickness, 2 feet in length, spaced 1⅛ inch apart; interchange surface, 7·5 square feet	15 20·3	45·5 45·5	169 147·5[1]
3	Same as (2), with baffle-plates introduced to circulate the water	6·1 19·25	37 43	172·5 133[1]
4	Spiral of 38 feet of copper tube, ¾ inch in diameter, $\frac{1}{50}$ inch in thickness, in an annular vessel; interchange surface, 7·5 square feet	11·5	46	174
5	Tubular interchange-vessel, six 2-inch tubes, $\frac{1}{16}$ inch in thickness, 22⅜ inches in length, spaced 2⅜ inches apart; interchange surface, 5·9 square feet	5 13·2	45 45	189 172·5
6	Same interchange-vessel as (2), with only ten tubes, spaced 2¼ inches apart; interchange surface, 4 square feet . . .	7·3	48	172·5
7	Mean results of experiments made on plant of 5,540 gallons capacity. Thickness of tubes, $\frac{1}{50}$ inch; interchange surface, 6,200 square feet	5,540	57	191
8	Leavesden Asylum plant; copper tubes 2 inches in diameter; thickness 18 S.W.G.; interchange surface, 8,649 square feet	9,000	52	191

[1] In these cases the water was

DIX.

SOFTENING AND STERILIZING APPARATUS.

Temperature of Hot Sterilized Water.	Temperature of Cold Sterilized Water.	Heat Units taken up by Unsterilized Water per Square Foot of Interchange Surface per Hour.	Heat Units lost by Sterilized Water per Square Foot of Interchange Surface per Hour.	Column G corrected to a Temperature Difference between Inflow and Outflow (col. F—col. C) of 20° F.	Time taken for Water to pass through apparatus.
Column E.	Column F.	Column G.	Column H.	Column L.	Column M
°F.	°F.	B.Th.U.	B.Th.U.	B.Th.U.	Minutes.
206	53	1,250	1,300	$1,250\times\frac{20}{16}=1,560$	7½
208·5	81·5	2,770	2,840	$2,770\times\frac{20}{36}=1,540$	3
208·5	80	2,410	2,570	$2,410\times\frac{20}{34\cdot5}=1,400$	3½
189[1]	84·5	2,760	2,830	$2,760\times\frac{20}{39}=1,410$	2½
204	53	1,100	1,230	$1,100\times\frac{20}{16}=1,380$	8
171[1]	79	2,310	2,360	$2,310\times\frac{20}{36}=1,280$	2·5
208·5	69·5	1,960	2,130	$1,960\times\frac{20}{23\cdot5}=1,670$	5·5
208·5	57	1,220	1,280	$1,220\times\frac{20}{12}=2,030$	24
208·5	77	2,850	2,940	$2,850\times\frac{20}{32}=1,780$	9
205	77	2,270	2,340	$2,270\times\frac{20}{29}=1,570$	10
212	72·9	1,200	1,240	$1,200\times\frac{20}{15\cdot9}=1,510$	20
212	73	1,450	1,450	$1,450\times\frac{20}{21}=1,380$	40

not boiling in the boiling-vessel.

(*Paper No. 3615.*)

"The Filtration-Works for supplying the Town of Alexandria with Potable Water."

By Henry Robert Cecil Blagden.

The completion of the filtration-works described in this Paper marks an important epoch in the modern history of Alexandria, and even of Egypt, as the works are the first of their kind in that country, and Alexandria is the first town in Egypt to be supplied with an efficient and up-to-date filtration-system for its water-supply.

For more than 10 years various schemes for the improvement of the water-supply have been discussed by the Water Company and the Municipality, and about 4 years ago it was practically decided to adopt a large system of slow sand-filtration, consisting of two large settling-tanks containing one day's supply, or about 7 million gallons, together with twelve filter-beds, each 1,436 square yards in area; towards the cost of this installation it was agreed that the Municipality should contribute a large portion, and the Water Company a fixed sum of £10,000. Before commencing the work, however, it was necessary to spend about £6,000 in levelling off a suitable site of about 12 acres at the back of the waterworks, where it was intended to construct the settling-tanks and filters. This levelling was actually done by the Municipality and was completed about the end of 1902, but beyond this, with the exception of a few preliminary drawings and estimates, nothing further was done, and the whole question was in abeyance, owing to the financial position of the Municipality at that time.

In September, 1902, the Water Company and the Municipality jointly were approached by the Jewell Export Filter Company of New York, with a view to the introduction of their system of rapid sand-filtration, but at first the suggestion was received with a good deal of opposition, not only because the slow sand-system had been practically decided upon, but also because the Water Company and the Municipality together had already spent some years in carrying

out experiments on this system with some small settling-tanks and filters which had been specially made for this purpose. The Jewell Filter Company, however, gave extremely favourable guarantees as to the saving in first cost of the new works by the adoption of their system, and also the higher efficiency of their filters as compared with that which probably would be obtained with the slow sand-filters; they were further prepared to substantiate their guarantees by erecting, on their own responsibility and at their own expense, in Alexandria, near the Water Company's intake on the Mahmoudieh Canal, a complete model plant, including pumps, settling-tanks, and one Jewell gravity-filter capable of delivering 22,400 gallons of filtered water in 24 hours. This plant was actually delivered and erected in October, 1902, and trials and bacteriological tests were then carried out by Dr. H. Bitter, Director of the Egyptian State Institute of Hygiene, Cairo, and Mr. E. A. Gieseler, representing the Jewell Export Filter Company, in the presence of the officials of the Water Company and Dr. E. Gotschlich, representing the Municipality. The results of these trials were so conclusive, proving that even the guarantees had been exceeded, that there was no doubt in the minds of all concerned, both from the mechanical and bacteriological point of view, that it was a decided improvement on the slow sand-system, and that it was particularly well adapted for dealing with the Nile water and for the requirements of the town of Alexandria. The ultimate result of these trials was that the previous convention of 1895 between the Municipality and the Water Company was cancelled, and new designs and estimates were at once prepared by the Author for the whole scheme, including the Jewell Company's estimate for their part of the work; this estimate, including the cost of filters, settling-tanks, new boilers, new pumping-engines, auxiliary engines, new buildings, pipework, alteration of existing engines, alteration of existing buildings, etc., was submitted by the Water Company to the Municipality in May, 1903, the Water Company offering, as contractors, to carry out, complete, and be responsible for the whole of the work, undertaking to have it finished within a period of 2 years from the signing of the new convention. The total amount of the estimate was £78,300, of which it was decided that the Municipality should pay a fixed sum of £61,500 irrespective of any excess that might be incurred by the Water Company in carrying out the work, the remainder to be paid by the Water Company. The final convention was signed on 29 July, 1903, it being agreed that the whole installation, with the exception of an extra clear-water reservoir, should be completed and put to work within 2 years from that date.

Advantages of the Jewell System.—There can be no doubt that, for a town like Alexandria, which is unfortunately occasionally visited by an epidemic of cholera, the Jewell system of filtration presents many great advantages over the slow sand-system. It requires only about one-sixth of the area of the ground required for the same daily output by the slow sand-system. The cleaning out and washing of the filters is done entirely mechanically, without any handling whatever and without any man coming in contact with the filtering-sand, whereas in the slow sand-system at least thirty men would be employed in scraping the top layer of sand in the filters for cleaning purposes, and in times of epidemic there would be considerable risk of infecting the filters; anyone who is acquainted with the extremely insanitary habits of the natives will thoroughly appreciate this point. The Jewell filters are contained in a covered house, and are not exposed to the hot sun and dust; this is an important point in Egypt where masonry-work, especially cement, deteriorates and cracks very rapidly from exposure to the sun, and requires constant repairs; all the valves and automatic regulating-apparatus are also within the filter-house, and consequently can be easily kept clean, besides being far less liable to get out of order. The whole of the washing of the filters can be easily done by one man, each filter occupying only 5 minutes per day in cleaning, and not only the top layer of the filter, but the whole bed of sand, is cleaned at each washing; the Jewell filter is also in itself an ideal sand-washing machine, as will be explained later. Lastly, it can be justly claimed for the Jewell filter that it possesses an almost ideal regulator for the speed of filtration, and for the pressure; the flow of filtered water is absolutely constant during the entire run, and the diagram of pressure is perfectly regular, as has been shown by constant experiment. This is a most important fact, as it is well known that the perfect working of a sand-filter depends entirely upon the constancy of the rate of filtration and the regularity of the increase of pressure. The Weston automatic controller on the outlet likewise has the advantage that the rate of filtration, in case of necessity, can be changed in a few minutes; this is of great importance in the event of a sudden demand for an abnormal quantity of filtered water, due to an outbreak of fire or other cause.

General Description of the Works.—The main pumping-station and filtration-works of the Alexandria Water Company are situated on the outskirts of the town, on the main road to Ramleh and Aboukir, the area of ground covered being 11·6 acres, Fig. 1, Plate 7. The grounds are conveniently and tastefully laid out, and contain, in addition to the works, the residences of the Managing Director,

Chief Engineer, foremen and engine-drivers, and also a large stock-yard for pipes and other materials. This pumping-station has to supply filtered water for a population (according to the last census, taken in 1901) of nearly 400,000 people, including natives, and the daily consumption of water ranges, according to the time of year, between 4½ million gallons and 8 million gallons, the maximum consumption being at the time of year when the condition of the water in the Nile is at its worst, and consequently throws a maximum amount of work on the filters. The Company supplies more than 15,000 private services, which are rapidly increasing, and in addition it provides water for the poorer native population at fountains which are distributed all over the native quarters, the water being sold in skins containing about 16 gallons, which are carried on men's backs and distributed from house to house. The source of water-supply is the Mahmoudieh Canal, the nearest point of which is about ¾ mile from the works. This canal was made about the year 1819, when Mahomed Aly was Khedive, and takes off from the Nile at a place called Atfeh, near Rosetta, about 45 miles away; it is used not only for irrigation of the Delta, but also for navigation between Alexandria and Cairo and intermediate towns and villages. When it is realized that this canal is the receptacle for all the refuse and other impurities from the navigation, and also to a large extent for the drainage of nearly all the villages situated along its banks, it will be readily understood how necessary it is for the health of the inhabitants of Alexandria that every care should be taken with the treatment of the water before delivering it into the town.

The Water Company have their intake from the Mahmoudieh Canal at a point about ¾ mile from the main pumping-station, and have a small pumping-station at the intake for raising the water from the Mahmoudieh into their own private canal, known as the Farkha Canal, the difference in level varying between 5 feet and 10 feet according to the variations of level in the Mahmoudieh. From this point the Farkha Canal runs direct to the main pumping-station, in the latter part of its course passing under the main road, through a large masonry-culvert of about 6 feet 6 inches by 3 feet 3 inches in cross-section, and thence into three collecting-wells immediately in front of the main engine-house, from which the low-service pumps take their suction. The water is raised from these wells by the low-service pumps and delivered through a 30-inch main to the settling-tanks, where it has a rest of at least 6 hours under the influence of a solution of sulphate of alumina which is injected into the 30-inch main half-way between the pumping-

station and the settling-tanks; after leaving the settling-tanks the water passes through a 36-inch main to the filter-house and finally into the clear-water reservoirs, whence it is pumped by the high-service pumps into the service-reservoir at Kom-el-Dick, against a head of about 87 to 90 feet.

Settling-Tanks.—The settling-tanks, three in number, are situated at the back of the main pumping-station on a piece of land granted by the Egyptian Government to the Water Company for their new works; this piece of ground has been taken into the waterworks grounds and inclosed by a stone wall, the old boundary-wall having been removed. The tanks are designed to hold 985,000 gallons each, and are arranged as shown in Figs. 1 and 2, Plate 7. There is a circular distributing-basin at one end, containing about 55,000 gallons, into which the whole of the unfiltered water is pumped by the various low-service pumps from the Farkha Canal; this distributing-basin is in direct communication with each of the three settling-tanks, being connected by three 24-inch pipes and sluices to enable any tank to be shut off when required. The unfiltered water, previously to its arrival at the distributing-basin, has already been subjected to treatment by sulphate of alumina in solution, which will be described later. Each settling-tank is provided at the inlet-end with a semi-circular basin, 22 feet by 11 feet, having the same depth as the settling-tanks and communicating with the settling-tanks at the bottom; each settling-tank is also divided half-way up its length by two masonry-walls, each 2 feet in thickness, one wall acting as a baffle-wall, and the other—that nearer the inlet—as a weir; the latter has no openings in it except a wash-out valve which is always kept shut when the settling-tanks are working; the baffle-wall is provided with eight openings at the bottom, through which the water passes from the first compartment into the second, after having passed over the middle weir already referred to. The second compartment is of exactly the same capacity as the first, and is provided at the outlet-end with a masonry outlet-weir the whole width of the tank, over which the top film of the settled water passes into a semi-circular outlet-basin, 22 feet by 11 feet, whence it passes through a 30-inch sluice-valve into a 36-inch main leading to the filters. In addition to this outlet-weir there are also provided two cast-iron adjustable weirs, each 9 feet in width, of special design, and working in gun-metal guides; these weirs, under normal conditions, are kept at the same level as the masonry-weirs, and can be lowered 12 inches, if necessary, in the event of the water becoming low in the settling-tanks, due to a sudden draw-off by turning on

additional filters, or until the engine-attendant has time to increase the speed of the low-service pumps so as to bring the water in the settling-tanks to its normal level. Under ordinary circumstances the level of the water never varies more than 3 inches, every inch of variation being accurately recorded by a special electrical instrument indicating on a dial, and at the same time recording on a diagram in the main pumping-station, so that the rate of filtration and the rate of pumping the unfiltered water are identical.

The variation between the day- and night-supply for the town is compensated by the clear-water reservoirs, so that the rate of filtration and number of filters used can remain the same during the 24 hours. In preparing the ground for the foundations of the settling-tanks it was found that practically the whole surface of the ground was undermined and honey-combed with old disused wells and culverts, which had probably belonged to the former town of Alexandria and had served for its water-supply; a considerable amount of money, therefore, had to be expended in solidifying the soil so as to ensure a solid bed for the foundations. It was obvious from the beginning that the only way to arrive at this was to arrange for an extensive flooding of the whole area after the excavations were completed; consequently a temporary 16-inch pipe was laid as far as the middle of the excavations and pumping was continued intermittently for a period of 50 days and nights, representing, according to the engine-counter, about 250,000 tons of water. Considerable subsidences at once became evident, and for more than 30 days such subsidences had to be filled up from time to time until no further signs of settlement were evident, and the water stood about 2 feet in depth over the whole area. After the soil had become more or less dry on the surface, the whole area was rolled over with a 16-ton steam-roller which gave a far greater pressure per square foot than the soil would ever be subjected to by the weight of the masonry and the water in the tanks. The whole surface, therefore, was thoroughly well pressed before any concrete was put in.

The walls and bottoms of the settling-tanks were made much thicker and considerably heavier than was necessary to resist the mere water-pressure, in view of the very uncertain condition of the sub-soil. Hydraulic cement-concrete was used throughout, mixed in the following proportions:—Lime and pozzolana (Santorin), mixed $\frac{2}{3}$ pozzolana and 1 lime, 2 parts; sharp sand, washed and screened, 6 parts; Portland cement, 1 part. The substance of the concrete consists entirely of ancient broken pottery (Chakf), which is found locally in immense quantities, and is particularly well suited for concrete-work on account of its practically flat sides and sharp

angular edges, which afford an excellent bond. In spite of the comparatively low rate of labour in Egypt, a considerable amount of machinery was employed in connection with the concrete-making. The pozzolana and lime were ground together in edge-runners and afterwards screened, the refuse of the screen being returned to the edge-runners, so as to ensure a perfect mixture of the two materials. The broken pottery or Chakf was screened by means of two large rotatory screens arranged with two rings of $\frac{3}{4}$-inch mesh to remove any dust, and two rings of $2\frac{1}{2}$-inch screen consisting of perforated steel plate through which the Chakf passed; all refuse from these screens was broken in a Blake stone-breaker to the required size. The mixing of the concrete was done in the following manner, commonly known as the French method: the Chakf was measured out on mixing-tables, about 13 feet by 7 feet, double-boarded to prevent leakage, and the mortar, having been previously mixed wet in a pug-mill, was added in a wet state; the whole was then thoroughly mixed by hand-labour before being used on the work. A complete system of light railways was installed for the transport of the material, in order to expedite the work as much as possible. With the exception of the bottom of the basins the whole of the concrete-work, including side-walls, end-basins, and weirs, was formed in wooden centering; this centering constituted one of the most difficult parts of the work, on account of the somewhat peculiar shapes required. The amount of concrete in the settling-tanks is approximately 13,000 cubic yards. The concrete-work was commenced on 18th April, 1904, and was completed by the end of September, giving an average of about 78 cubic yards per day, including Sundays. The inside of the settling-tanks was rendered with cement-plaster, in two layers, having a total thickness of $\frac{3}{4}$ inch, the first rendering being about $\frac{1}{2}$ inch in thickness and composed of 3 parts of sharp sand to 1 part of Portland cement; the surface of this layer was left rough to form a good keying for the finishing layer, which was composed of 1 part of sand to 1 part of Portland cement. The whole surface of the bottom of the tanks was lined with a layer of bituminous asphalt, $\frac{3}{8}$ inch in thickness, applied hot, thus rendering it absolutely water-tight and impervious to leakage. The asphalt was covered with 2 inches thickness of fine concrete and cement-rendering to form a protection against damage when cleaning out the settling-tanks. The inside surfaces of all the walls were treated on completion with the well-known Sylvester process, consisting of the application of a solution of soap and water, followed by a solution of alum and water, which, when applied in two or three coats, has the effect of entirely closing the pores of the

cement-rendering, and consequently prevents any moisture creeping through the masonry; this is especially desirable when the retaining-walls stand out of ground and are exposed to view, as on these works.

Filters.—The filters, eighteen in number, are of the Jewell Export Filter Company's gravity-type, Figs. 3 and 4, Plate 7. Each filter is 17 feet in diameter, giving 226 square feet of filtering surface, and consists of a substantial riveted steel tank, 7 feet in height, containing the filtering-sand, about 3 feet in depth, supported in the ordinary way by a layer of fine gravel. The collecting of the filtered water is done in the following manner:—At the bottom of the tank there is a large cast-iron header, about 8 inches in diameter, which passes through the shell of the tank to the outlet-branch; this header is provided with a number of wrought-iron branch-pipes screwed into the body and plugged up at the outer end; the header and the branch-pipes are bedded in concrete and rendered with cement so that their top surfaces just appear above the top of the rendering; they are drilled and tapped at intervals of about 6 inches or 8 inches, and fitted with 900 small brass screens standing vertically, and having perforated sides of copper sheet securely fixed into the bodies of the screens. These screens stand up vertically in the gravel and take the whole of the filtered water as it passes through the filter-bed, and there is practically no waste water-space in the bottom of the filter for the filtered water to become stagnant, all the space between the pipes being entirely filled up with concrete. The shell of the filter is surrounded around the upper portion by an outer shell, leaving an annular space of about $5\frac{3}{4}$ inches all round the filter; this outer shell is carried up about 2 feet above the filter-shell, and allows the settled water from the settling-tanks to enter the filter without in any way disturbing the filtering-surface of the sand.

The settled water enters through an 8-inch nozzle into the annular space, and flows over the rim of the filter-shell around the whole circumference. The filtered water leaves the filter through the small screens already described, and thence passes through an automatic regulating "Weston" controller, by means of which the effluent is automatically kept absolutely constant and the working-pressure of the filter is regulated. The condition of the filtering-surface is recorded automatically by means of a loss-of-head gauge, which indicates when the filter requires washing by arriving at the point corresponding to the greatest possible pressure under which the filter will give its full quantity of water.

The washing of the Jewell filter is extremely simple and quickly

performed, one man only being required for the whole operation, whereas with the old slow sand-filters a considerable staff of more or less skilled workmen is required to scrape off the top layer of the filter-bed, in which the greater part of the impurities is retained. In washing a Jewell filter, the inlet- and outlet-valves of the filter are closed, and the washout-valve draining the annular space is opened, carrying off the unfiltered water standing above the top rim of the filter-shell. The wash-water valve is then opened, admitting filtered water into the main outlet-header at the bottom of the filter and distributing it under pressure through all the 900 screens already referred to, whence it rises up through the whole bed of sand. The whole of the filtering-skin is broken up by the pressure of the rising water, and the mud and other impurities rise to the rim of the filter-shell and are carried away into the annular space, which is open to the main drain for the dirty water. At the same time a revolving agitator, consisting of a large rake having prongs about 2 feet 6 inches in length, is operated by means of shafting and belting driven by the same engine that drives the wash-water pump; by means of this agitator and the simultaneous flow of the wash-water, the whole of the sand and the clogged upper layer is stirred up in a most effectual manner, all the impurities attached to the sand being washed away, leaving the actual sand-grains, on account of their greater specific gravity, behind in the filter. The washing of the filter may be considered to be completed when the wash-water running over the annular space becomes fairly clear, the time occupied in washing a filter being usually 4 to 5 minutes. The direction of the agitator is then reversed and the loose rakes leave the vertical position; the wash-water is shut off and the sand-bed again becomes solid, so that the loose rakes lie on the top surface of the sand; the agitator is then stopped and the filter can be put to work again by admitting the unfiltered water. When the unfiltered water has arrived at its normal height above the sand, a rewash-valve is opened to waste, allowing the effluent coming from the filter to run to waste for 10 or 15 minutes as may be found necessary to remove any slight turbidity which must necessarily be left in the filter after washing. After this period the rewash-valve is closed and the delivery is opened, admitting the effluent to the outlet-controller which delivers directly into the clear-water reservoir below. The whole operation, not including the time required for rewashing, only occupies 6 minutes for washing and operating the valves.

The filters are erected on circular cement-concrete foundations, built up from the bottom of the clear-water reservoir and projecting

through the covering of the reservoir, so as to give the filters the desired elevation; they are arranged in two batteries, viz., one battery of ten filters and one of eight filters, with six spare foundations, so that six additional filters can easily be added when necessary, thus making a total of twenty-four filters, arranged in two batteries of twelve filters each.

Wash-Water Tank.—In connection with the washing-arrangements for the filters there is provided a circular steel tank, 34 feet in diameter by 10 feet in depth, mounted on a strongly-braced steel structure and containing 50,000 gallons of filtered water at an elevation varying between 30 feet and 40 feet above the tops of the filters. This tank is erected at some little distance from the filters, and is connected by a 12-inch pipe to the wash-water pipes inside the filter-house. Water for filling this tank is supplied by the 10-inch centrifugal pumps in the auxiliary engine-house, to be described later; the tank is covered in at the top, and has a covered gangway all round, so that it is well protected from the strong rays of the sun.

Filter-House.—The filters are contained in a handsome brick building, 138 feet by 103 feet, constructed of Italian bricks, Figs. 5, Plate 7. The main structure of the building is of special design, and consists of two bays, each having eight principals in the whole length, resting on cast-iron columns built into the side-walls, and in the middle on light steel columns which rest on the bottom of the clear-water reservoir. The support of the weight of the roof is therefore entirely independent of the masonry, which, in consequence, is made as light as possible; the roofing is of Lysaght galvanized sheeting. The filter-house is provided with an upper floor, known as the operating-floor, which stands about 12 inches below the tops of the filters, and is accessible from both main entrances by handsome ornamental cast-iron staircases. From this floor all the work of operating the filters is performed; the spindles of the operating-valves of each filter are continued up through the floor, and are each provided with a valve-post, on which are fixed a brass name-plate bearing the name of the valve, and a brass index-gear to indicate whether the valve is open or shut. An automatic reservoir-gauge is provided above the operating-floor so that the attendant knows at any moment the exact amount of water in the clear-water reservoir.

Clear-Water Reservoirs.—The clear-water reservoir under the filters is subdivided into three distinct compartments, any one of which can be shut off and cleaned out without disturbing the others. The bottom of this reservoir is made in hydraulic cement-concrete of the same materials as the settling-tanks. The whole of the clear-

water reservoir, both inside and outside the filter-house, is covered with "expanded metal" and cement-concrete, supported on steel girders and cast-iron columns, a sufficient number of inspection-traps being provided for getting down into the reservoir. On that part of the covered reservoir which is outside the filter-house the concrete is covered with a layer of asphalt, ¾ inch in thickness, which renders the covering impervious to water and prevents leakage of dirty water into the reservoir. Two additional clear-water reservoirs are provided on the other side of the main pumping-station; these were originally slow sand-filter beds, but have been entirely reconstructed, the side-walls having been underpinned all the way round and new concrete bottoms put in. These reservoirs are also covered over with "expanded metal" and cement-concrete. The three clear-water reservoirs together contain 1,760,000 gallons of filtered water, which is about ¼ day's supply for the town.

Auxiliary Machinery.—Immediately outside the filter-house, and on the top of the clear-water reservoir, is an engine-house, 52 feet by 27 feet, by 37 feet in height, containing the auxiliary machinery in connection with the filter-plant, and on the upper floor the alum mixing-apparatus and chemical laboratory, Figs. 6, Plate 8. The engine-house is built entirely of Italian bricks to correspond with the filter-house and other buildings of the waterworks. The plant on the ground-floor consists of two sets of Belliss and Morcom quick-revolution engines, each of 70 I.HP., with their own surface-condensing plants standing in the basement and driven by belt. The condensing-plants were made by Messrs. Isaac Storey and Company, of Manchester; each plant consists of a surface-condenser, having 200 square feet of cooling-surface, fitted with an Edwards air-pump and a 3½-inch centrifugal circulating-pump which takes its water from the clear-water reservoir and discharges back into the same reservoir through the condenser. The Belliss engines are arranged with extended bedplates and two outer bearings carrying continuations of the crank-shafts on which are mounted two pulleys, one for driving a 10-inch Sulzer high-lift centrifugal pump, and the other for driving a countershaft which drives a dynamo for lighting purposes; this countershaft also drives, by means of belting, the whole of the shafting in the filter-house, in connection with the revolving agitators on the filters. The driving-pulleys on the crank-shafts are fitted with Bagshaw friction-clutches, which render it quite easy to start the centrifugal pump or the transmission-shafting without altering the speed of the engine. The Sulzer pumps, which are used for the filter-washing, are of the high-lift type, capable of delivering 1,000 gallons of water per minute

against a head of 60 feet; they take their suction from the clear-water reservoir immediately underneath them, and deliver the water up to the wash-water tank, which supplies the filtered water under pressure for washing the filters, as already described. In the corner of this engine-house there is a large alum-store capable of holding about 80 tons of sulphate of alumina. In connection with the wash-water tank there is a Kent electrical recording-instrument fixed on the wall, which records every inch of rise and fall of the water in the tank. On the upper floor of this building there is a chemical laboratory, equipped with every requisite for the bacteriological examination of the water, which is made every day, and also the coagulant-feed apparatus.

Sulphate of Alumina Coagulant Feed.—The coagulant feed is of special design and has a capacity sufficient for twenty-four filters; it is so arranged that any number of filters from one to twenty-four can be properly supplied with the desired quantity of coagulant, Figs. 7, Plate 8.

In preparing the coagulant, the sulphate of alumina is hoisted up from the store-room in the basement of the building to the coagulant-room; on arriving at the platform around the coagulant-tanks it is weighed on a weighing-machine, and is then picked up by a small overhead transporter carrying a tip-bucket and carried along over the tops of the coagulant-tanks to any desired position; by releasing a catch the alumina is tipped on to the dissolving-tray, fixed in the top of each coagulant-tank. These coagulant mixing-tanks, three in number, for preparing the sulphate of alumina coagulant are made of cypress-wood. Each tank is 8 feet in diameter and 7 feet 6 inches in depth internally, and one tank only is in use at a time. Under each coagulant-tank there is a sheet-lead tray, having a lead drain-pipe leading from it, to drain away any leakage there may be from the tanks. In each mixing-tank, near the top, is fitted a shallow box for dissolving the sulphate of alumina; the bottom of this box is composed of slats of wood, placed about $\frac{1}{8}$ inch apart, through which the water rises and comes in contact with the sulphate of alumina. A suitable and substantial wooden platform surrounds the mixing-tanks, and two flights of steps lead up to the platform from the floor of the coagulant-room. The pipes and fittings for supplying the filtered water to the mixing-tanks are of unusually large diameter, in order that they may be able to furnish the requisite quantity of water with a good flow. Each mixing-tank is fitted with a hard-rubber float, actuating an indicator which moves at the side of a graduated rod in front of the tanks, so that the attendant can observe the level of the solution in any one of the

tanks from the floor. A small steam air-compressor supplies air under pressure for stirring up the solution in the mixing-tanks, and is kept working continuously, although only very slowly.

The coagulant flows from the mixing-tank in use, through hard-rubber piping and fittings (specially made to withstand the action of the alum) to a cypress-wood gravity-box, fitted with three hard-rubber ball-cocks for keeping the level of the coagulant in it constant. The gravity-box is also provided with a hard-rubber overflow, and two perforated copper screens between the inlet-cocks and the discharge-orifice. From the gravity-box the coagulant flows by gravity through a hard-rubber pipe and graduated regulating-cocks into a series of funnels fitted into the upper ends of stand-pipes. The stand-pipes are connected with a receiving-pipe, whence the coagulant flows through a 2-inch lead pipe to the 30-inch rising-main for the unfiltered water, half-way between the main pumping-station and the settling-tanks, at which point it is injected into the centre of the 30-inch main through a brass nozzle. The actual amount of sulphate of alumina required to effect a satisfactory clarification varies somewhat with the condition of the water and the time allowed for sedimentation. It has been found that in these works, with the particular form of settling-tank adopted, and with 6 hours' sedimentation, excellent results, in respect of both clarification and bacteriological purification, are obtained with 15 to 22 parts by weight of sulphate of alumina per million parts of water treated.

Main Pumping-Station.—The original pumping-station, which was built about the year 1860, remains very much the same so far as the building is concerned, although it now contains practically none of the original machinery. The present pumping-plant consists of two compound condensing beam-engines, with high-pressure cylinders 18½ inches in diameter by 3 feet 8 inches stroke, and low-pressure cylinders 30 inches in diameter by 5 feet 6 inches stroke; each engine is arranged with a high-service filtered-water pump on one side of the beam and a low-service unfiltered-water pump on the other side. Each high-service pump is capable of delivering 3,300,000 gallons per 24 hours against a head of 90 feet, and the low-service pumps, which were originally ten per cent. larger than the high-service pumps for the old system of filtration, have now been replaced by smaller pumps, on account of the additional height to which the unfiltered water has to be raised to reach the settling-tanks. The low-service pumps take their suction directly from the Farkhà Canal and deliver it into the settling-tanks against a gross head of 52 feet. The high-service pumps take their suction from the

clear-water reservoirs and deliver it through a 20-inch and 24-inch main to the service-reservoir at Kom-el-Dick against a gross head of 90 feet. There are also installed two compound beam-engines working on one crank-shaft, the high-pressure cylinders of each engine being $18\frac{1}{2}$ inches in diameter by 3 feet $1\frac{1}{2}$ inch stroke, and the low-pressure cylinders 29 inches in diameter by 4 feet 6 inches stroke; they work one high-service double-acting plunger-pump, 25 inches in diameter by 3 feet 10 inches stroke, and one low-service pump of similar construction, $26\frac{1}{2}$ inches in diameter by 3 feet 10 inches stroke, directly from the beam; these engines are now somewhat out of date and are merely used as a stand-by. The engines described above were all made by Messrs. Easton and Anderson, London, and have been at work about 25 years.

No new machinery was added until $2\frac{1}{2}$ years ago, when it was found necessary on account of increasing demand to instal some more powerful and more economical engines; accordingly, two triple-expansion pumping-engines were added (Figs. 8, Plate 8), one for high-service and one for low-service; each set is capable of delivering 6 million gallons in 24 hours. These two engines were manufactured by Messrs. Douglas and Grant, of Kirkcaldy, N.B. The engines are of the vertical, marine-type, condensing, the high-service engine having cylinders 14 inches, 22 inches, and 33 inches in diameter, by 36 inches stroke, and the low-service engine having cylinders 12 inches, $18\frac{3}{4}$ inches and 30 inches in diameter by 36 inches stroke; in other respects the two engines and pumps are exactly similar. The pumps are of the three-throw single-acting plunger-type, having plungers $22\frac{5}{8}$ inches in diameter by 36 inches stroke; the plungers are worked directly from the cross-heads of the piston-rods by means of two steel side-rods, one on each side of the crank-shaft, the crosshead being set askew to allow the rods to clear the crank-shaft. The plungers are of special construction, hollow, and fitted internally with a trunnion-bearing to take the bottom ends of the connecting-rods, the top ends of which are connected with the crank-pins. The crank-shafts are of typical marine-type, made of mild steel throughout and built up of separate units; the cranks are set at angles of 120° to one another. The cylinders are all jacketed, the jackets of the high-pressure and the intermediate-pressure cylinders being supplied with steam at the full pressure of 160 lbs. per square inch, and that of the low-pressure cylinder with steam at a pressure of 50 lbs. per square inch, through a reducing-valve; all the jackets are automatically drained into the hot-well by means of Geipel steam-traps. The pistons are of cast iron and are fitted with Buckley packing-rings, and all the piston-rod glands are packed with United States

metallic packing. The high-pressure cylinders are fitted with Corliss valve-gear having a special knock-out attachment in connection with a powerful governor, which is set to pull off a trigger and put the trip-gear out of action when the engines are running three revolutions per minute more than their intended speed. The Corliss gear is also fitted with a brass index-plate and a small hand-wheel by means of which the expansion can be varied, so that the speed can be regulated to a nicety by the driver by varying the cut-off in the high-pressure cylinder. The intermediate and low-pressure cylinders are fitted with slide-valves and expansion-valves; the valves are not of the usual design, but are divided up so that each end of the cylinder has its own valves, and thus a considerable amount of clearance is economized: the expansion-valves are fitted with Meyer gear, which admits of the rate of expansion being adjusted while the engines are running. All the main bearings and eccentrics, connecting-rod ends, etc., are provided with grease lubrication instead of oil, and a great saving in cost is effected. The cylinder-lubrication is supplied by a Manzell positive force-pump, having a separate pipe to the steam-chest of each cylinder, so that the oil may be fed to one or all of the cylinders simultaneously. The cylinders and steam-chests are thickly lagged with mica and asbestos cloth, and are cleaded all over with planished steel sheets held in place by polished steel bands.

In connection with these two engines there is a separate surface-condensing plant common to both engines; the condenser is of cylindrical form and of ordinary construction, having a cooling-surface of 675 square feet. The air-pump, of the Edwards type, has cylinders 12 inches in diameter by 12 inches stroke, and is arranged side by side with a double-acting circulating-pump of ordinary design, having cylinders 13 inches in diameter by 12 inches stroke; these two pumps are driven directly by a small compound vertical engine, having cylinders 4½ inches and 7 inches in diameter by 12 inches stroke, running at 70 revolutions per minute; the engine being fitted with a heavy fly-wheel, and having its cranks set at right-angles, there is no difficulty in starting it. The exhaust-steam from this engine passes through a Royle feed-water heater inserted in the main feed-pipes, so that the greater part of the heat of the exhaust-steam is utilized in heating the feed-water.

These two engines were tested for duty, coal-consumption, etc., on 27th November, 1904, by the Author in the ordinary course of work and without any special preparation, so that the results are such as could be obtained any day under ordinary working conditions. Having regard to the fact that the heads of water are comparatively

low, and therefore do not admit of a very high mechanical efficiency, they may be considered very satisfactory. The following are the mean results obtained from the high- and low-service engines running together:—

Mean boiler-pressure above atmosphere . . .	157 lbs. per sq. in.
Average speed, high-service engine	28·9 revolutions per minute.
„ „ low-service „	31·2 „
Total number of revolutions, high-service engine	17,500
„ „ „ „ low-service „	18,900
Duration of trial	605 minutes.
Average gross head, high-service pumps . . .	88·93 feet.
„ „ „ low-service „ . . .	62·01 „
Total coal consumed, including ashes (88 lbs.) .	3,520 lbs.
Combined work done by the two pumps during trial	4,277,621,600 foot-lbs.
Combined duty per cwt. of coal	136·23 million foot-lbs.
Total water evaporated by boiler during trial, including air-pump, engine, steam-traps, etc. .	35,134 lbs.
Water evaporated per hour	3,485·46 „
Water evaporated from actual temperature per pound of coal	9·98 „
Water evaporated from actual temperature per pound of combustible.	10·23 „
Average temperature of steam at outlet of super-heater	503° F.
Grate-area of furnaces	27·50 square feet.
Evaporation per square foot of grate per hour .	12·69 lbs.
Average temperature of water at economizer inlet	158° F.
„ „ „ „ outlet	221° F.
Average power of the two engines combined, taken from four sets of indicator-diagrams. .	253·80 I.HP.
Average combined power developed by pumps .	215·50 HP.
Mechanical efficiency	84·9 per cent.
Coal per I.HP.-hour	1·37 lbs.
Coal per water-HP.-hour	1·62 „
Steam per I.HP.-hour	13·7 „
Steam per water-HP.-hour	16·12 „

There are also in the same engine-room two low-service engines and pumps made by Messrs. Douglas and Grant, each capable of delivering 3,700,000 gallons per 24 hours, of unfiltered water from the Farkha Canal, to the settling-tanks, against a head of 52 feet. These pumps are two-throw double-acting plunger-pumps, 15 inches in diameter by 20 inches stroke, running at forty to fifty revolutions per minute, and are driven directly off the cross-heads of two vertical compound marine-type condensing engines, having cylinders 10 inches and 20 inches in diameter by 20 inches stroke, and a working steam-pressure of 160 lbs. per square inch. The cranks are set at right-angles and on each crank-shaft there is a heavy fly-wheel

weighing $3\frac{1}{2}$ tons, the cranks being balanced by metal in the rim of the fly-wheel. The high-pressure cylinders are fitted with Corliss valve-gear and automatic knock-out gear similar to that on the triple-expansion engines already described; the low-pressure cylinders are fitted with a single slide-valve worked by an adjustable eccentric, so that the cut-off may be varied as required. Each engine has its own surface-condenser cast in the back A-frames; the circulating-water is taken directly from the low-service rising-main; an Edwards air-pump, having barrels 6 inches in diameter by 6 inches stroke, is driven by a rocking-lever from the high-pressure cross-head, which also drives a small feed-pump, $1\frac{1}{2}$ inch in diameter by 6 inches stroke. A feed-water heater is fitted in the exhaust-pipe, between the low-pressure cylinder and the condenser. These engines and pumps work with remarkable smoothness, and at a speed of fifty revolutions per minute the pumps are perfectly noiseless. The engines are fitted with a substantial entablature and cylinder-platform surrounding them, corresponding in design to those of the triple-expansion engines previously described.

Boilers.—The boilers, four in number, are situated in the boiler-house adjoining the main engine-room. They are of the ordinary Lancashire type, 7 feet in diameter by 25 feet in length, each having two flues 2 feet 9 inches in diameter. At the back of each boiler, and on the top of the back flue, is fitted a Schmidt flue-fired super-heater, which superheats the steam up to 550° F. or nearly 190° F. above the temperature of saturated steam at a pressure of 160 lbs. per square inch, which is the working-pressure in the boilers. The superheaters are of very simple construction, and are made of a series of solid-drawn serpentine steel coils, connected at each end to a special cast-steel header. Each superheater is arranged in two compartments divided by a middle wall, each compartment being filled with the heating-coils. The saturated steam is admitted into the bottom of the coils in the second compartment, or at the part furthest away from the boiler-furnace, and consequently the coolest part of the superheater. From this point it rises to the top of the second battery of coils, whence it passes into the top of the first battery and is taken down to the bottom of these coils, or the hottest part of the superheater. The superheated steam then passes through the cast-steel headers, to which the coils are connected, and thence into the steam-pipe leading to the engines. The regulation of the temperature of the superheated steam is extremely easy, and is effected by moving a damper which regulates the amount of furnace-gas passing through the superheater. The gases, after leaving the superheaters, pass along a back flue, 6 feet 6 inches by 2 feet 9 inches,

to a Green economizer, having eighty tubes, and thence to the main chimney. The boilers are heavily lagged with Leroy non-conducting composition, and the steam-pipes and flanges with sectional magnesia-lagging bound with canvas on the outside. Two Weir feed-pumps are installed in the boiler-house, but are only used in cases of emergency, as all the main engines are fitted with their own feed-

RESULTS OF FILTRATION. THE CHEMICAL, PHYSICAL, AND BACTERIOLOGICAL RESULTS OBTAINED DURING THE MONTHS OF AUGUST, SEPTEMBER, AND OCTOBER, WHEN THE NILE WATER IS AT ITS WORST, ARE GIVEN IN THE FOLLOWING TABLE:—

Test.	Raw Water.	Decanted Water.	Filtered Water.
1. Total residue on evaporation at 212° F. to 230° F. Milligrammes per litre	222·5	135·0	147·5
2. Total hardness (soap method). Milligrammes Ca CO_2 per litre.	50·0	54·0	58·0
3. Chlorine (by titration with silver nitrate). Milligrammes per litre	8·0	8·9	8·0
4. Ammonia	Slight trace	..	..
5. Nitrates (tested with brucine)	Trace	Trace	None.
6. Organic matter (by titration with potassium permanganate). Milligrammes oxygen consumed per litre	3·8	2·0	1·7
7. Carbonic acid, bound (computed as 44 per cent. + 44 per cent. = 88 per cent. of the alkalinity expressed as milligrammes Ca CO_2 per litre formed by titration with lacuerid) . .	91·5	86·2	86·2
8. Carbonic acid, free (by titration with sodium carbonate and phenol phthaleine). . . .	3·7	7·5	8·0
9. Total carbonic acid (found by addition of Nos. 6 and 7). Milligrammes CO_2 per litre . .	95·2	93·7	94·2
10. Transparency. August. (Depth of water in which a thick platinum wire vanishes.) Centimetres	0·07	0·20	>200·0
Transparency. September. (Depth of water in which a thick platinum wire vanishes.) Centimetres	0·03	0·18	>200·0
Transparency. October. (Depth of water in which a thick platinum wire vanishes.) Centimetres	0·023	0·19	>200·0
11. Bacteria in 1 cubic centimetre. August. (Removal of bacteria 99·51 per cent.) . .	2,016	237	10
Bacteria in 1 cubic centimetre. September. (Removal of bacteria 98·84 per cent.) . .	3,791	669	44
Bacteria in 1 cubic centimetre. October. (Removal of bacteria 98·74 per cent.) . .	3,489	583	44

pumps. At the back of the boiler-house a large coal-store is provided, having a capacity of about 1,000 tons, and the coal is brought into the stoke-hole on a small light railway, the trucks passing over a small weigh-bridge so that each load is weighed on its way into the stoke-hole. The coal employed is the best Welsh steam-coal that can be obtained, the furnaces and firebars being specially designed for this fuel.

Recording-Instruments.—Considerable care has been taken to provide thoroughly reliable electrical recording-instruments for recording the levels of all the various reservoirs, including the main service-reservoir at Kom-el-Dick, the settling-tanks, the wash-water tank, and the clear-water reservoirs. These instruments, which are extremely reliable and well finished, were made by Mr. George Kent, London; they are placed in the main engine-room so that the driver can observe at a glance the exact level of the water in any of the reservoirs to within 1 inch. The instruments are also fitted with an alarm-bell, which rings automatically when the water is either too high or too low in any particular reservoir, and so gives warning to the engine-driver.

The foregoing results leave no room for doubt as to the efficiency of the method of sedimentation and filtration; the action of the alumina in the settling-tanks is most marked, and it has been found when cleaning out the settling-tanks that the amount of deposit remaining in the first compartment of the settling-tanks was nearly five times that in the second compartment, showing that the time allowed for sedimentation, which at present is 7 to 9 hours, is amply sufficient. The percentage removal of bacteria from the raw water is distinctly high, and exceeds the guarantee of the Jewell Filter Company; the daily averages are very uniform, and never since the first month of the filter's working has the removal of bacteria been less than 98 per cent.

Cost of the Works.—The estimated cost of this filter installation, including two new boilers, two sets of low-service pumps, alterations to existing machinery and buildings, new buildings, settling-tanks, pipe-work and valves, auxiliary machinery, filters and accessories complete, two covered clear-water reservoirs, etc., was £78,300, and in spite of several unforeseen contingencies this sum has not been exceeded in carrying out and completing the work.

The preliminary drawings and arrangement, all estimates and specifications, and the detail-drawings for the whole of the works, with the exception of the actual filters and the alumina feed-apparatus, were prepared by the Author, who also had entire charge of the

execution of the work, which was carried out without a contractor. The designs for the Jewell filters and accessories were prepared by Mr. E. B. Weston, M. Inst. C.E., the Consulting Engineer to the Jewell Export Filter Company, New York; whilst the filters were erected and put in operation under the direction of Mr. R. W. Lawton, superintendent of construction to the same Company.

The Paper is accompanied by nine tracings, from which Plates 7 and 8 have been prepared.

(*Paper No. 3616.*)

"The Formation of a Concrete Well-Lining by Cement-Grouting Under Water."

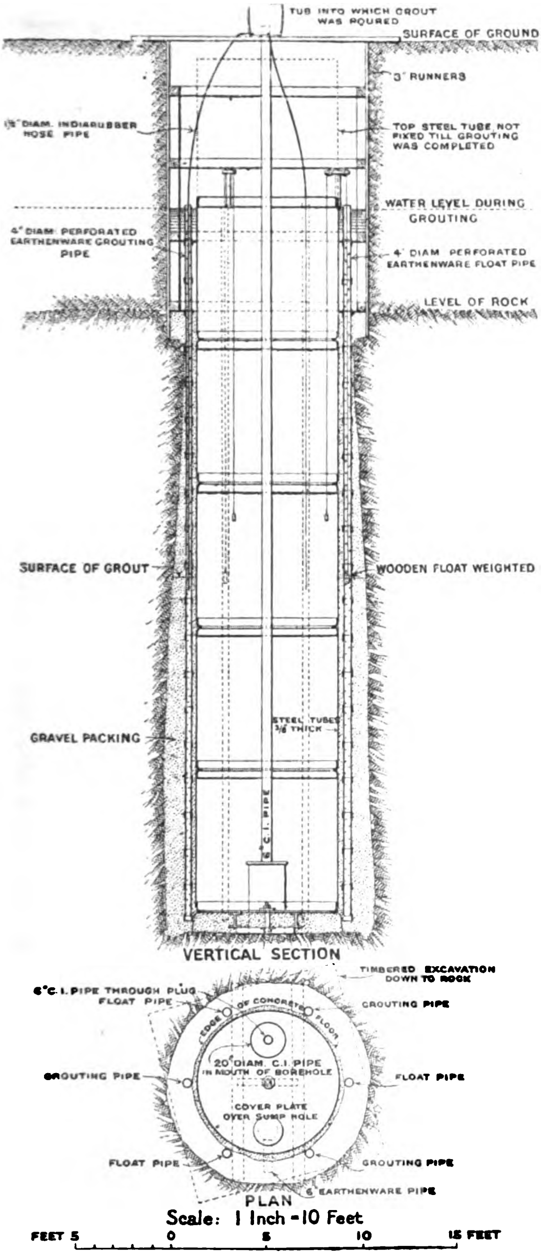
By Robert William Vawdrey, B.A., Assoc. M. Inst. C.E.

The work described in the following Paper illustrates one of the almost innumerable uses to which Portland-cement grout may be put. The method of carrying out the work was partly suggested by the Paper[1] on "The Use of Cement Grout at the Delta Barrage in Egypt," by Sir R. Hanbury Brown, K.C.M.G., M. Inst. C.E., read before the Institution in 1904.

About 5 years ago the Kidderminster Corporation decided to increase their water-supply, and a new well about 10 feet in diameter was sunk to a depth of 50 feet, the last 35 feet being through New Red Sandstone rock, *Figs. 1.* From the bottom of this well a bore-hole 20 inches in diameter was carried down for a further depth of 250 feet, and a plentiful supply of water was obtained. Steel tubes, 8 feet in diameter and 8 feet in length, were provided for lining the upper portion of the well. For various reasons it was then decided to postpone the completion of the scheme, and the matter remained in abeyance until the beginning of 1905, when it was decided to proceed with the erection of new pumping-plant, etc., and to utilize the above-mentioned well and steel lining. The well is situated not far from the River Stour, and the surrounding ground is saturated to a level of only a few feet below the surface, the level varying of course with the state of the weather. A centrifugal pump which had been originally installed to deal with this surface-water had been left in the well and had consequently become so badly corroded as to be useless when work was recommenced; pulsometer pumps were therefore requisitioned. The old timbering which supported the top 15 feet of gravel and soil was also in a very bad state, and had to be renewed. In the top of the bore-hole at the bottom of the well a cast-iron pipe had been inserted

[1] Minutes of Proceedings Inst. C.E., vol. clviii, p. 1.

Figs. 1.


TUB INTO WHICH GROUT WAS POURED
SURFACE OF GROUND
3" RUNNERS
1½" DIAM. INDIARUBBER HOSE PIPE
TOP STEEL TUBE NOT FIXED TILL GROUTING WAS COMPLETED
WATER LEVEL DURING GROUTING
4" DIAM. PERFORATED EARTHENWARE GROUTING PIPE
4" DIAM. PERFORATED EARTHENWARE FLOAT PIPE
LEVEL OF ROCK
SURFACE OF GROUT
WOODEN FLOAT WEIGHTED
GRAVEL PACKING
STEEL TUBES 3/8 THICK
6" C. I. PIPE
VERTICAL SECTION
TIMBERED EXCAVATION DOWN TO ROCK
6" C. I. PIPE THROUGH PLUG
FLOAT PIPE
EDGE OF CONCRETE FLOOR
GROUTING PIPE
20" DIAM. C.I. PIPE IN MOUTH OF BOREHOLE
GROUTING PIPE
FLOAT PIPE
COVER PLATE OVER SUMP HOLE
FLOAT PIPE
GROUTING PIPE
6" EARTHENWARE PIPE
PLAN
Scale: 1 Inch = 10 Feet
FEET 5 0 5 10 15 FEET

and fitted with a plug, through which a 6-inch pipe was taken up the well to the surface of the ground, the water from the bore-hole rising in this pipe to an average level of 5 feet above the level of the surrounding surface-water, although on Sundays (owing no doubt to the cessation of pumping in a number of other wells in the district, from which water is drawn for manufacturing purposes) it often poured out of the top of the 6-inch pipe at a level above the surface of the ground. It is therefore clear that the surface-water cannot contaminate that which is tapped by the bore-hole at a depth of 300 feet. As the surface-water is liable to a considerable amount of pollution, it was essential that the steel tubes forming the lining of the well should be absolutely water-tight, and as they were also intended to support the pump-barrels it was considered necessary that the space surrounding the tubes, between them and the rock sides of the well, should be firmly packed with concrete. The construction of this concrete presented difficulties, as it was found when the well was emptied that a large quantity of water exuded from the rock, chiefly in small jets from fissures, the force of the jets becoming very considerable towards the bottom of the well. To place concrete between the rock and the steel tubes in the ordinary way was impracticable, as the cement would have been carried away by the moving water.

It was therefore decided that the space surrounding the tubes should be packed with gravel as the tubes were fixed in position, and that this gravel should be subsequently converted into concrete by grouting with liquid cement when the water should have been allowed to rise to its natural level in the well, and would therefore be at rest.

A concrete floor was formed while the well was kept dry by pumping, and the bottom length of tube was then lowered into position. The space outside the tube was then packed with gravel, and the remainder of the tubes were placed in position one above the other, the space surrounding each tube being packed with gravel. The pump was drawn up as the work proceeded, the water being allowed to rise so that the level was kept just below each joint as it was being made. As the gravel packing was put in, six columns of 4-inch earthenware pipes, perforated with ½-inch holes, were placed in it at equal intervals around the well, the object of these pipes being to facilitate the subsequent grouting process. In order to ensure these columns of pipes being kept vertical while the gravel was being packed round them, a wooden rod was inserted in each, and fastened by clips to the top edge of each steel tube in turn, the rods being drawn up and refixed in position when the next

tube was lowered. This process was continued until the steel lining had been completed to a level above that of the surface-water in the ground, the whole space between the steel and the rock being packed with gravel. The water in the interstices of the gravel was now at rest, the jets which had previously issued from the rock being neutralized by the pressure of the water in the gravel. It was arranged that grout should be poured down three of the earthenware pipes, the other three being used to contain floats, which consisted of wooden blocks adjusted by means of lead weights, so that they would float in cement-grout, but would sink in water. A line was attached to each float and was passed over a small pulley fixed on the top edge of the steel lining, a small balance-weight being attached to the other end, which hung down inside the well. The purpose of the floats was to indicate, during the process of grouting, the exact level to which the grout had risen in the interstices of the gravel. As the float-pipes were at the farthest possible distance from the grouting-pipes, the rising of the floats also indicated that the grout had spread through all parts of the gravel. For the actual process of grouting, a rough timber stage was constructed at ground-level, across the top of the well, and on this was placed a tub about 2 feet in diameter and 2 feet in depth, *Figs. 1.* Three india-rubber hose-pipes, each 1½ inch in diameter and 50 feet in length, were led from the bottom of this tub down the three grouting-pipes, and the grout was poured into the tub by means of buckets, after being mixed by hand in iron troughs placed near. The grouting was continued without intermission, and occupied 12 hours. To avoid any possibility of the hose-pipes becoming choked, the grout was all poured through a fine sieve placed on the top of the tub, and little difficulty was experienced in getting the grout to flow regularly. As the surface of the grout rose in the interstices of the gravel, the hose-pipes were continually shortened by cutting off about 3 feet at a time, so that the grout might be delivered from their ends at or near the surface between the grout and the water, and so that any disturbance of the grout already in position might be avoided. The grouting-pipes were 10 feet apart, so that the grout had to travel 5 feet through the gravel in each direction to reach a float-pipe, and in order that there should be no difficulty in this the gravel was all screened, only that being used which was retained on a screen of ¾-inch mesh. As a result it was found that the floats rose quite uniformly, and that there was hardly any appreciable difference between the levels of the grout in the float-pipes and in the grouting-pipes. There is therefore little doubt that a considerable admixture of finer gravel

might be retained with safety, thus effecting a considerable savin in the cement required to fill the interstices. The volume of th space surrounding the tubes was carefully measured before bein packed with gravel, and this was checked by taking notes of th amount of gravel used, the quantity being 54 cubic yards. Th interstices in the screened gravel were found by experiment t amount to 39 per cent. The total volume of water in the grave was therefore 39 per cent. of 54 cubic yards, *i.e.* 569 cubic feet. I had been previously found by experiment that one volume of cemen (shaken together in its dry condition) mixed with one volume o water formed $1\frac{1}{4}$ volume of grout, which finally set to a block whos volume was almost exactly 1, *i.e.* the original volume of the dr cement, the surplus water remaining uncombined. The volume o cement actually used in grouting the gravel was 587 cubic feet making, when mixed with water in the ratio of 1 to 1 by volume, about 750 cubic feet of grout; the volume to which this grout finally set being 569 cubic feet, plus a small quantity which would no doubt enter the small fissures and holes in the sandstone rock, the actual result is seen to agree closely with that obtained by experiment. On account of the shrinkage in setting (namely from 750 cubic feet to 587 cubic feet) the level of the grout as indicated by the floats had to be brought sufficiently high above the required finished level to allow the settlement to take place, the extra height necessitated being about 8 feet. The surface of the water during the process of grouting was 8 feet above the top of the gravel, which was at the finished level required. As the whole of the ground surrounding the well was subsequently excavated to this level for the purpose of constructing engine-foundations, it became possible to examine the top of the concrete formed in this way, and it was found to be perfectly satisfactory. No doubt the concrete formed at the bottom under a head of nearly 50 feet of water would be still stronger.

It may be mentioned that it was found by experiment that in whatever proportions cement and water be mixed (provided there is sufficient water to form liquid grout), the amount of water finally taken up by the cement is always approximately the same, and the volume of the material when set depends therefore only on the amount of cement used, not on the quantity of water mixed with it, the final volume of the cement when set being approximately equal to the volume of the cement when shaken together in the dry condition. When, however, cement is mixed with the minimum quantity of water, say 20 per cent. of its original dry volume, it sets to about 75 per cent. of the original volume, and it is therefore to be

expected (as indeed proves to be the case) that grout when set, although quite satisfactory for such work as that described in this Paper, should not be as strong as cement mixed with a minimum quantity of water, as the same quantity of cement sets to a volume 25 per cent. smaller in the latter case than in the former.

The Engineers for the work were Messrs. Willcox and Raikes, for whom the Author acted as Resident Engineer, and to whom he is indebted for permission to publish the information contained in this Paper. The contractors were Messrs. T. Vale and Sons, Limited.

The Paper is accompanied by a tracing, from which the Figure in the text has been prepared.

(Abstract of Paper No. 3625.)[1]

"The Specific Gravity of Portland Cement."

By David Butler Butler, Assoc. M. Inst. C.E.

The specific gravity of Portland cement has long been considered a test of its quality, and is specified as such in the recently-issued British Standard Specification. It is held to denote the degree of calcination to which the cement has been subjected in the course of manufacture, a high specific gravity indicating a thoroughly burned material, and *vice versa*; it is also considered to indicate adulteration with materials of different specific gravity.

It is well known that, owing to absorption of water and carbonic acid (having specific gravities of 1·0 and 0·88 respectively), the specific gravity of cement decreases with age, or after aeration, but the Author was surprised to find that, after ignition at red heat to expel the water and carbonic acid and to reduce the material to practically the same condition as regards these substances as when it left the kiln, the specific gravities of various cements were so nearly identical as to render the test of little or no value as an indication of quality. The results of preliminary experiments with thirty different cements, having specific gravities varying between 3·026 and 3·138 (*i.e.* a difference of 0·112), showed that after ignition the specific gravities differed by only 0·016, which is well within the range of experimental error in ordinary technical determinations.

In order to test the generally accepted theory that specific gravity is an indication of the degree of calcination, twenty-eight samples of black well-burned and yellow under-burned clinker from the same kiln or charge were obtained from various works, and the specific gravity of each sample was ascertained (1) in the condition in which it was received, and (2) after ignition at red heat. The results showed that all the yellow under-burned samples, when they had absorbed any appreciable amount of water and carbonic acid, had a much

[1] The complete Paper, with its accompanying Tables and Appendix, may be seen in the Library of the Institution.

lower specific gravity than the well-burned samples, but that after ignition at red heat the specific gravities of the well-burned and under-burned materials were practically identical, indicating that the difference was merely due to absorption of water and carbonic acid. A notable fact in connection with this series of experiments was that, out of thirteen samples of yellow under-burned material fresh from the kiln, no less than eight would have fulfilled the requirements of most ordinary specifications for well-burned cements, as regards specific gravity. The subject was therefore investigated further, and instead of merely ascertaining the total loss on ignition before determining the specific gravity, the percentage of water and carbonic acid was estimated separately. This was done with forty-one different cements, which were not in any way specially chosen for the purpose, but were ordinary samples passing through the Author's hands in the usual course of his practice. The samples were afterwards classified for more convenient reference, and comprised English, Belgian, and German artificial Portland cement; Belgian natural cement; cement produced by the lately-introduced rotatory kilns; and also cement adulterated with various adulterants. In all these experiments the result was practically the same. Samples which in their commercial condition differed widely in specific gravity, were found to have practically the same specific gravity when "loss free," *i.e.* after ignition at red heat, and consequent expulsion of the water and carbonic acid absorbed since calcination. This similarity suggested that, having ascertained the percentage of water and carbonic acid contained in the ignited sample, and the specific gravity of the "loss free" material, it should be possible to deduce the specific gravity of the unignited sample; or, in other words, given the specific gravity of the material in the condition in which it left the kiln, its specific gravity after it has absorbed given amounts of water and carbonic acid should be determinable by means of a formula. This formula was found to be :—

$$\frac{1}{\text{unignited specific gravity}} = (0\cdot0080 \times \text{percentage of } H_2O) + (0\cdot0055 \times \text{percentage of } CO_2) + \frac{100 - (\text{percentage of } H_2O + \text{percentage of } CO_2)}{100\,(\text{ignited specific gravity} - 0\cdot048)}$$

In several of the Tables accompanying the Paper a column is added giving the specific gravity calculated from this formula, which is found to agree very closely with the actually determined specific gravity, thus proving the Author's contention that the specific gravity

of cement depends entirely upon absorption of water and carbonic acid.

The main body of the experiments having been made with ordinary commercial samples containing comparatively little water and carbonic acid, additional experiments were made with two cements of first-class quality, which had been exposed to the atmosphere for 80 days, during which period they had been periodically examined, and had finally absorbed water and carbonic acid to the extent of about 10 per cent. altogether. The result was the complete corroboration of previous experiments, showing as before that the specific gravity depended entirely upon the water and carbonic acid absorbed, which could be exactly allowed for by calculation. Based on these experiments, calculations have been made of the decrease in specific gravity for each 1 per cent. of water or carbonic acid absorbed; the results are shown in the following Table:—

Calculated Specific Gravity of Portland Cement.

(Assuming ordinary cement free from gypsum), if aerated with (1) water only, and (2) carbonic acid only.

	Specific Gravity after ignition	0 Per Cent.	1 Per Cent.	2 Per Cent.	3 Per Cent.	4 Per Cent.	5 Per Cent.	6 Per Cent.	7 Per Cent.	8 Per Cent.	9 Per Cent.
(1) Water only. .	3,248	3·200	3·151	3·103	3·057	3·012	2·969	2·927	2·885	2·894	2·804
(2) Carbonic acid only	,,	3·200	3·167	3·152	3·129	3·106	3·083	3·061	3·039	3·017	2·996

These experiments having been conducted in a somewhat more careful manner than those first described (*i.e.* rather as a matter of scientific research than of ordinary technical determination), it was thought advisable to verify the results obtained in the first instance with well-burned and under-burned clinker, and further samples, twenty-three in number, were therefore obtained, representing practically the entire English cement industry. The results fully corroborated the previous experiments in every respect, and fully demonstrated the fact that the degree of calcination in no way affects the specific gravity when the clinker is fresh from the kiln.

Having regard to the difference in apparent density and weight, between the black well-burned and the yellow under-burned clinker, the porosity of small pieces of each degree of calcination was determined, and showed that the porosity of the yellow under-burned clinker was 66·65 per cent.; of the intermediate clinker 57·2 per cent.; and of the well-burned clinker 22·6 per cent.; in

other words, 9 parts by volume of yellow under-burned clinker become on further calcination 7 parts of intermediate and 4 parts of well-burned clinker.

For purposes of reference the chemical analyses of all the samples of cement used in the experiments are given in an Appendix to the Paper.

Briefly summarized the conclusions which may be drawn from the experiments are:—

(1) That the specific gravity of Portland cement is no indication whatever of proper calcination.

(2) That the specific gravity of Portland cement depends upon its age, and the opportunities which it has been afforded of absorbing water and carbonic acid from the atmosphere.

(3) That the specific gravity of Portland cement, although of no use in determining calcination, may sometimes be of corroborative value in determining slag and other adulteration.

(4) That, given the specific gravity of the ignited sample, and the percentage of water and carbonic acid expelled by ignition, the specific gravity of the unignited material may be calculated with a fair degree of accuracy.

(*Paper No. 3621.*)

"The Milan Navigation Congress of 1905; and Italian Navigation Works and Ports Visited."

By Leveson Francis Vernon-Harcourt, M.A., M. Inst. C.E.

The Tenth International Navigation Congress was inaugurated b His Majesty the King of Italy, accompanied by the Queen, in th Scala Theatre at Milan, on the morning of the 25th of September 1905; and in the afternoon the ordinary meetings of the Congres were commenced in the Villa Reale, a royal residence on th outskirts of the town. The Author had the honour of attending th Congress as the delegate of the Institution, as well as serving a a representative of the British Government, in conjunction wit Colonel Sir Charles M. Watson, K.C.M.G.; and this Paper on th visits to works at the conclusion of the proceedings at Milan, has bee prepared at the special request of the Secretary.[1]

Visits to Works.

Visits to lake and river navigations, comprising the oldest an newest navigable lateral canals of Northern Italy, and to two of th most important hydro-electric power-stations in the neighbourhood were made on two days during the session of the Congress at Milan After the close of the proceedings, two tours of inspection wer organized, one to the River Po and the Port of Venice, with it outlet-channels into the Adriatic at Lido, Malamocco, and Chioggia and the other to the harbour-works at Genoa, Spezia, and Naples which form the subject of this Paper.

[1] The original Paper, as deposited in the Institution, contains a summary of th proceedings of the Milan Congress, supplemented by an Appendix giving a list o the questions submitted to the Congress and the conclusions arrived at, and a comparison of the number of Papers presented with those of previous navigation congresses; and it also gives concise accounts of the visits to works in the neighbourhood of Milan during the Session of the Congress. A second Appendix,

The River Po.

The River Po, by far the largest inland waterway of Italy, was visited by members of the Congress after the close of the session in Milan, who went along it for a few miles by steamer between Pontelagoscuro and Polesella, on their way to inspect Chioggia and the Port of Venice, as well as the two other outlet-channels from the Venetian lagoons.

The river rises on Monte Viso, and traverses Northern Italy from west to east in a length of about 417 miles, flowing through the centre of the extensive plains of Lombardy, and receiving numerous tributaries coming down from the Alps and the Apennines; it has a basin of 26,780 square miles, of which 15,847 square miles are mountainous regions and 10,933 square miles are plains; and owing to the 35 million cubic yards of detritus, on the average, carried down in a year by the river from the mountains to the sea, its basin is increased each year by about 333 acres by the advance of its delta into the sea. The ordinary flow of the Po at Pontelagoscuro, about 57 miles from the sea, is 60,745 cubic feet per second; whilst the discharge of the greatest flood that has been measured, in October, 1868, was 220,870 cubic feet per second, though a higher flood occurred in October, 1872, which caused widespread inundations. The bed of the Po consists of pebbles and gravel down to about the confluence of the River Trebbia, 137 miles below Turin, of sand from thence to Borgoforte, 101 miles farther down, and of silt or mud along the remaining 111 miles to the mouth of the river. The average fall of the Po, which is 8¼ feet in a mile between Turin and Casale, is reduced to 3 feet in a mile between Casale and the confluence of the River Tanaro, and to 2 feet between Casale and the Ticino; whilst the surface velocity of the river at the low stage in this section, 102½ miles long, ranges between 6½ and 5 feet per second. From Ticino to Cavanella di Po, a length of 224 miles, the average fall is 9½ inches in a mile, and the surface velocity varies from 5 feet per second at Piacenza to 20 inches at Cavanella; and from Cavanella to the sea, along the Tolle branch, a distance of 22⅓ miles, the fall is under 2 inches per mile, but is influenced by the tide, which is felt above Cavanella.

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moreover, describes the position and functions of the Permanent International Association of Navigation Congresses, the remarkable amount of support accorded to it by foreign Governments and public bodies, and the prominent part it takes in the arrangements for the triennial sessions. Owing, however, to the limited space available in the Minutes of Proceedings, these portions of the Paper have been omitted in its published form.

Navigation.—Between Turin and Casale, navigation is almost impracticable on account of the large fall and the weirs at Chivasso and Casale for directing the water into the Cavour and Lanza irrigation-canals, thereby diverting almost all the water during the low stage away from the river. Moreover, the river winds considerably and shifts its bed for most of the distance below Casale to the confluence of the Ticino, and does not become fairly stable till a little farther down;[1] whilst the depth in this section at the ordinary low stage varies between 4 feet and 16½ feet. The navigation, indeed, in this section only begins regularly at the confluence of the River Sesia, about 6⅔ miles below Casale; and this part of the river is regarded as a second-class waterway in affording a normal depth of between 3¼ and 6½ feet. The portion of the Po from the confluence of the Ticino down to Cavanella, 224 miles long, with depths at the ordinary low stage ranging for the most part from 8⅓ feet to 19⅔ feet, is the most important in respect of navigation, and the best adapted for it, possessing an ample depth, except over a few shoals, found generally at the confluence of the turbid tributaries from the Apennines coming in on the right bank, or in unduly wide parts of the river, or where the channel crosses over between two bends on opposite banks. These shoals prevent full advantage being taken of the remarkably favourable flow of the Po for navigation, owing to the main influx into it of the tributaries from the Apennines occurring in winter and spring, and of the tributaries from the Alps in summer and autumn. Moreover, though most of this portion of the Po is reckoned as being a first-class waterway, implying a minimum navigable depth throughout of 6½ feet, the shoals reduce the assured navigable depth to 4 feet, only allowing of the passage of barges of 120 tons; but this navigation is only liable to be hindered or stopped during an average of 77 days in a year, by the lowness of the water, by floods, by fog, or other exceptional causes. The last section of the river, from Cavanella to the sea, being entirely comprised within the delta of the Po, which at the present time commences at the divergence of the Goro branch from the river about 9 miles above Cavanella, is of less importance commercially than the long central portion above, though it possesses an ample depth, except over the bar in front of the Tolle outlet, where the depth is reduced to between 2¼ feet and 2⅔ feet at high tide.

Embankments along the River Po.—Floods are retained within the

[1] "Atti della Commissione per lo Studio della Navigazione Interna nella Valle del Po. Relazione Quarta: il Po da Torino al Mare," Plate vii. Rome, 1903.

river-banks down to Gerola Bridge, 89 miles below Turin, except at a few low places which have been embanked; but from this point embankments have been formed along both sides of the river down to its outlet, having lengths of 268½ miles along the right bank and 261 miles along the left bank, to protect the riparian lands from inundation. Parts of the embankments were carried out below Cremona long ago, and have been gradually extended both above and below; but during the flood of 1872 they were overtopped in several places, and thirty-three breaches formed, through which the river inundated large areas of land. The Po, however, has since risen higher in some places than in 1872, as, for instance, in 1879, when large breaches were formed, in 1886, and in 1887; whilst the embankments have been only partially raised above the flood-level of 1872. The raising of the bed of the Po by the deposit of materials brought down by the torrential tributaries into the river flowing slowly across the Lombardy plains, has been disputed; but assuming that the longitudinal sections of the river from Turin to the sea in 1874 and 1901, accompanying the report of the Commission of 1903, were taken under comparable conditions, it is evident that the bed of the river has been materially raised since 1874 from the confluence of the Ticino to below Cavanella.[1] Under these conditions, any further restriction of the high floods by raising the embankments would only sooner or later aggravate the injuries caused by the inundations, owing to the raising of the river-bed, and consequently the flood-level, by confining the detritus brought down from the mountains, instead of allowing it to spread over the adjacent plains.

Dredging in the River Po.—With the view of removing the shoals which at present restrict the navigation between the Ticino and Cavanella, experiments were recently undertaken with a suction dredger at places in the Po above the confluence of the Taro, the Oglio, and the Panaro, along a total length of 1¾ mile, when about 180,000 cubic yards of materials were removed, at an average cost of 2¾*d.* per cubic yard. The results of these trials were very satisfactory, especially at the two upper places, where the current remains fairly constant along the line of the trench formed in its direction; and by extending the operations across the various shoals which at present reduce considerably the available depth in this important section of the river, there is every prospect that the navigable condition of the river would be greatly improved.

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[1] "Atti della Commissione per lo Studio della Navigazione Interna nella Valle del Po. Relazione Quarta: il Po da Torino al Mare," Plate i.

NAVIGATION WORKS PROPOSED IN THE VALLEY OF THE PO, AND VENETIA.

Waterway from Venice to Milan.—The principal work contemplated consists in the establishment of a first-class waterway, with a minimum depth of 6½ feet, between Venice and Milan, for vessels of 600 tons. This is intended to be accomplished by deepening the channel across the lagoon from Venice to Chioggia, and then following along the existing canals past Brondolo, a portion of the Adige, from Cavanella d' Adige to Tornova, and along the Loreo Canal to the Po at Cavanella,[1] up the Po, deepened over the shoals, to the Adda, and up this river to Pizzighettone, and thence by a new canal,[2] with nine locks of large lift, passing by Lodi to the Pavia Canal in the vicinity of Milan, which goes to that town.

Works proposed for completing the System of Inland Waterways.—In addition to the principal waterway just referred to, various existing waterways in the plains of Lombardy are to be improved so as to be navigable for barges of 100 tons to 250 tons, according to their situation; and new canals are proposed to be constructed to complete the network and to put them in communication with the River Po. The chief of these new waterways are, a lateral canal to the Mincio to connect the isolated Lake Garda with Mantua, and from thence with the Po; a canal from Brescia to the Fusia Canal, so as to put the isolated Lake Isco in communication with the Oglio; a canal to join the Modena navigation with the River Panaro; and some channels to complete the waterways across the Venetian marshes.

Cost of proposed Extensions and Improvement of Waterways.—The estimated cost of the whole of the proposed works amounts to £4,722,000, the most expensive portions of which are the canal from the Adda at Pizzighettone to Milan, estimated at £1,144,000, works for connecting Lake Garda with the Po, £964,600, and the canals from Lake Isco to the Oglio, £320,000; whereas the deepening of the Po below the confluence of the Ticino, so as to afford a minimum depth throughout of 6½ feet, is estimated at £48,000.[3] Some of these works, however, would enable water-power to be utilized to

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[1] "Atti della Commissione per lo Studio della Navigazione Interna nella Valle del Po. Relazione Terza: da Venezia al Po," Plates ii and iii.

[2] *Ibid.* "Relazione Settima: Fiumi, Canali, e Laghi Navigabili di Lombardia," Allegata B, p. 173, Plates i, ii, and iii.

[3] Cozza et Berta, "Lacs, Fleuves, et Canaux de Navigation d'Italie," pp. 228–235. Milan, 1905.

the extent altogether of 48,570 HP., which would serve to reduce the actual expenditure.

Lengths eventually of the Waterways of Northern Italy.—The present length of the navigable waterways of Northern Italy is 1,733 miles, and this will be increased to 2,119 miles by the works. Of this latter length, 438 miles are to be made capable of accommodating vessels of 600 tons, 247 miles of which consist of the waterway between Milan and Venice, 726 miles are to be available for barges of 250 tons, 792 miles for barges of 100 tons, and 163 miles for barges of less than 100 tons.

Advantages to be derived from the proposed Works.—The proposed improvement and extensions of waterways in Northern Italy will provide a first-class waterway from Milan to Venice, to the great benefit of both these great centres of commerce, as well as the other important towns situated on the Po, a waterway for barges of 250 tons extending from the eastern frontier, past Venice, to Ravenna, and the connection of the isolated lakes Garda and Isco with the Po and all the other waterways; whilst Lodi, Brescia, Verona, Cremona, and other towns, at present devoid of access by water, will be put in communication with the entire system of waterways; Ferrara, Bologna, and Ravenna will be linked to the network by navigable waterways; and Vicenza, Treviso, Modena, and other towns will have their communications by water considerably improved.[1]

Port of Venice and its Lagoon.

Venice, owing to its excellent natural position, situated on an extensive lagoon, and well sheltered from the sea, though in close proximity to it, has been a renowned seaport for centuries.

Venetian Lagoon.—The lagoon extends from the diverted River Brenta on the south to the River Sile on the north-east, along a distance of about 33 miles, with a maximum width of 9⅓ miles. It has an area of 226½ square miles, of which, however, only 107 square miles are sufficiently below high-water of spring-tides to affect materially the volume of tidal water entering and leaving the lagoon each tide through the openings in the narrow fringe of coast separating the lagoon from the sea, where the rise of tide in this embayment of the Adriatic is 2 feet 3½ inches at equinoctial spring-tides, and 1 foot 3¾ inches at neap-tides. Numerous channels intersect the lagoon, which, converging to the outlets, assist in filling and emptying the lagoon

[1] "Atti della Commissione per lo Studio della Navigazione Interna nella Valle del Po. Relazione Generale," Plate i. Rome, 1903.

each tide, and serve for navigation between Venice and other places on the lagoon and the sea[1] (Fig. 1, Plate 9).

Two dangers require to be guarded against in such a lagoon, namely, the silting up of the lagoon by the alluvium brought into it by rivers, thereby gradually reducing the tidal scour which maintains the depth of the channels and their outlets, and the formation of breaches during severe storms in the narrow strip of land adjoining the sea, which, by increasing the number of outlets from the lagoon, would diminish the scour, and consequently the depth, of the channels through the existing outlets. To provide against the first injury, the rivers Brenta and Bacchiglione were diverted southwards outside the lagoon in the sixteenth century, so as to fall into the sea at Brondolo, though, owing to frequent breaches in the embankments of the Brenta, this river was readmitted into the lagoon from 1840 to 1896, in order to enable thoroughly complete and durable works for its permanent exclusion to be carried out, which necessarily, during that period, injuriously affected the lagoon. In the first half of the seventeenth century, by means of very extensive works, the Po was diverted away from the lagoon to the south and the Piave to the north, and the River Sile was led into the former bed of the Piave at the north-eastern extremity of the lagoon; whilst the smaller rivers which flowed into the lagoon were also excluded. Nevertheless, the drainage from 402,800 acres of land adjoining the lagoon still flows into it, as well as the discharge from a small branch from the River Sile; but though this inflow appears to be regarded as unfavourable in excluding tidal water, yet, considering that it is probably fairly free from alluvium, it must be valuable in reinforcing the ebb, and thereby helping in carrying out again to the sea the sand brought in by the flood-tide during storms. The narrow strip of land enclosing the lagoon has been protected on its sea-face in early times by wooden sheeting, subsequently by timber and rubble combined, and latterly by sea-walls of masonry and rubble.

The restriction of the tidal capacity of the lagoon by private persons, chiefly by enclosing water-areas by embankments for fishery purposes, has been checked to some extent by laws passed from time to time; but it has proved necessary to petition for a more stringent enactment to stop this cause of injury.

Port of Venice.—There is a naval arsenal at the eastern end of Venice with a basin and two graving-docks, having access to the main channel by the Maroni channel and thence to the Lido outlet.

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[1] Coen-Cagli et Bernardini, "Ports Maritimes de l'Italie," pp. 269–274. Milan, 1905.

The commercial port of Venice consists of a Commercial Basin with the Scomenzera Canal, at the western extremity near the railway, surrounded by quays and provided with railway-sidings, constructed in 1868–1880[1] (Fig. 2, Plate 9), and the old natural portions of the port, comprising the Giudecca Canal with its western end near the basin and running across the southern part of Venice towards St. Mark's Channel, the eastern outer portion of the port, in both of which vessels can lie at anchor. The total water-area of the port is about 445 acres; whilst there are depths of over 23 feet at ordinary high-water, and for the most part between 26¼ and 33 feet, in 50 acres of the Commercial Basin with the canal, in 160 acres of the Giudecca Canal, and in 104 acres of St. Mark's Channel. The quays have been gradually extended as required in the Commercial Basin and on the north side of the Giudecca Canal, so that whereas in 1880 there were only 1,136 lineal yards of quays, there are now 3,291 yards, the most recent and deepest of which are shown in Figs. 3, Plate 9,[2] nearly two-thirds of the length affording depths alongside of 26¼ to 28 feet; whilst on the Giudecca Canal there are 367 lineal yards of quays with depths of 29½ to 33 feet in front of them. The cost of construction of the Commercial Basin with its warehouses, railway-sidings, and connecting bridges, up to 1880, was £150,000; but the subsequent extension of the quays and sidings alongside the basin and canal, warehouses and sheds, hydraulic machinery and cranes, and electric cranes and lighting, have raised the total expenditure on this part of the port to £480,000.

As the trade of the port of Venice has risen from 960,330 tons in 1887 to 1,987,865 tons in 1904, and during the last five years has been increasing at the rate of about 65,000 tons a year, fresh accommodation is urgently needed; but the designs for extensions are complicated by the necessity of avoiding any works which might reduce the tidal capacity of the lagoon, or interfere with the influx and efflux of the tide. The most satisfactory, from this point of view, of the various proposals submitted, is the construction of a second basin bordering the lagoon near the end of the railway-bridge, to be reached by a prolongation of the Giudecca Canal, for receiving all merchandise in transit, especially coals, which would thereby relieve the existing quays of the commercial port and the railway of the most cumbersome goods.

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[1] "Ports Maritimes de l'Italie," pp. 282–293.

[2] The quays represented by sections A, C, and E, Fig. 3, Plate 9, were constructed with concrete deposited within frames; and sections B and F with caissons sunk by aid of compressed air.

Navigation Channels in the Venetian Lagoon.—The first work for improving the navigable communication in the lagoon, was the formation of a channel connecting the depression, or basin, facing the Malamocco outlet with that of Lido, undertaken early in the eighteenth century; whilst other channels have been since deepened and maintained by dredging. The principal channels of the lagoon at the present time are, the Grand Navigation Channel, with a depth of 34½ feet at ordinary high-water, connecting the eastern end of Venice and the naval arsenal with the Malamocco outlet-channel, nearly 9½ miles long; the Poveglia Channel, 28 feet deep and 1,100 yards long, branching off from the previous one near Malamocco village, serving as a quarantine station; St. Mark's Channel and the Giudecca Canal joining the Grand Navigation Channel to the Commercial Basin, having a combined length of 3½ miles and depths of 26¼ to 29½ feet; and, lastly, the branch from St. Mark's Channel to the Lido outlet-channel, 690 yards long and over 33 feet deep. These main channels, together with the Malamocco and Lido outlet-channels, 2,230 and 4,920 yards long respectively, have a total length of about 18 miles.

The minor channels of the lagoon have a total length of about 96 miles, comprising the numerous canals intersecting Venice in every direction, measuring altogether 11 miles; the various channels providing means of communication to numerous places and industrial establishments on the islands and borders of the lagoon; and the channels to the south and north connecting the lagoon with the inland waterways of the valley of the Po, and of the Venetian plains, respectively; and depths of 6½ feet to 13 feet are maintained in these channels by dredging.

Dredging has been carried on for a long period in the principal channels, and since 1841 in the minor channels of the lagoon; and the maintenance of the depth in those channels necessitates an annual removal of about 78,500 cubic yards of deposit, at a cost of £2,560 or 7·8*d.* per cubic yard. This dredging, however, does not merely maintain the depth of the channels, but also assists in preserving the tidal capacity of the lagoon. The navigation channels are marked by oak piles, driven singly or in clusters of two or more along the sides, at intervals of 164 feet to 230 feet.

Outlet-Channels from the Venetian Lagoon.—There are at the present time three outlets by which the channels of the lagoon have access to the Adriatic, namely, Chioggia near the southern extremity, Malamocco in a central position, and Lido to the north; and the action of the sea constantly tends to form a continuous beach across these outlets, which is only prevented by the influx and efflux of

the tide filling and emptying the large expanse of the lagoon. Accordingly, these outlet-channels, in their natural condition, are impeded by a bar outside, where the tidal current, being unconfined, loses to a great extent its scouring efficiency. No works having been carried out at the Chioggia outlet, it is only accessible to vessels of small draught; and till works were undertaken at Lido in 1882 to concentrate the tidal current, which was divided between three outlet-channels, into a single channel across the bar, the Malamocco outlet-channel, which had been deepened by jetties during the middle portion of the nineteenth century, formed the main channel for the trade of Venice (Fig. 1, Plate 9).

Chioggia Outlet-Channel.—Numerous little anchorages exist alongside the islands scattered over the lagoon; but the only other regular port besides Venice is Chioggia, which, till recently, consisted merely of some old quays along the canals intersecting the town, with a small depth of water in front of them, these canals serving mainly to connect the lagoon with the inland waterways of the valley of the Po. Quite recently, however, a basin has been formed close to the town, and partially lined with quay-walls having a depth of 23 feet of water in front of them. Nevertheless, as nothing has been hitherto done to concentrate the current across the bar outside, and the tidal capacity of the lagoon in the neighbourhood of the outlet was considerably reduced by deposits brought into it by the River Brenta in the 56 years during the progress of the diversion-works last century, the available depth of the Chioggia outlet-channel is too small to enable vessels of good draught to come alongside the new quays. The maritime trade, accordingly, of the fishery port of Chioggia has remained stationary, and has never exceeded 40,000 tons in a year. Works, however, have been recently proposed for deepening the outlet-channel at Chioggia similarly to the other two; and when this port becomes accessible to vessels of large draught, and the improvement and extensions of the waterways of the Po valley have been carried out, the trade of Chioggia is certain to develop considerably as being the natural outlet of the inland navigation traffic of the Lombardy plains.

Malamocco Outlet-Channel.—The improvement of the depth over the bar in front of the Malamocco outlet was carried out between 1839 and 1872, by means of fairly parallel jetties extended out seaward across the foreshore.[1] These works, by directing and concentrating the

[1] "Ports Chioggia, Malamocco, and Lido, and the channels leading to Venice," Admiralty Chart, London.

tidal current into and out of the lagoon across the bar, have provided a minimum depth of 31 feet in the outlet-channel at ordinary high-water, enabling vessels of large draught to reach Venice (Fig. 4, Plate 9). The northern jetty has been given a length of 6,962 feet, and the southern jetty 3,137 feet; and the width between the centre lines of the two jetties is 1,545 feet. The jetties consist of a rubble mound raised to ordinary high-water level, 28 feet wide at the top, with slopes of 1½ to 1, protected by large blocks at the outer end, and surmounted by a masonry superstructure 6½ feet high (Fig. 5, Plate 9). They cost £320,930, or £31 15*s.* 6*d.* per lineal foot; whilst the expenses of maintenance are about £640 annually. At ordinary tides the average velocity of the ebb-current through the jetty-channel is 2 feet per second.

It appears probable that by carrying the south jetty as far out as the other, and by shortening a little the groyne projecting from the south side of the outlet, the available depth might be still further increased.

Lido Outlet-Channel.—The success which resulted from the jetty-works at the Malamocco outlet naturally led to the construction of similar works for improving the Lido outlet, commenced in 1882 and not yet fully completed; but at Lido it was essential to lead the three somewhat conflicting outlet-channels of Lido, St. Erasmo, and Treporti, into a single channel guided by jetties across the foreshore. The jetties, accordingly, starting from the land side of the two side channels, Lido and Treporti, have been made to converge in front of the smaller central St. Erasmo Channel, so as to make the three channels combine into a single outlet-channel of the requisite width, which is then directed by the jetties, prolonged parallel to each other, into deep water[1] (Fig. 9, Plate 9). The length of the north-east jetty is 11,926 feet, and of the south-west jetty 10,351 feet; and the width between the jetties along their outer parallel portions is 2,970 feet. These jetties are very similar in construction to those of Malamocco, with a rubble base and small solid superstructure, the rubble base in this case being only 21 feet in width at the top, but raised 1 foot 8 inches above the ordinary high-water level; whilst the superstructure, which is 5 feet high, varies in width from 5 to 10 feet (Fig. 9, Plate 9). The rubble mounds are not quite finished, and 5,413 feet of superstructure have still to be built on the north-east jetty and 5,085 feet on the south-west; but it is estimated that the cost of the two jetties when completed will amount to £304,000, or

[1] E. Cucchini, "The Lido Entrance at Venice." Milan Navigation Congress, 1895, Section II, 4th Communication.

£13 13s. per lineal foot, the much smaller cost of these longer jetties, in proportion to their length, than those at Malamocco, being probably due to the shallower depth of the inner portion of the jetties, the smaller width of the rubble mound and dimensions of the superstructure in a less exposed site, and the better appliances available for the construction of the jetties of late years.

The jetties at Lido have already, in their unfinished state, produced an increase in the depth of the channel between them, from the original 10 to 13 feet up to from 23 to 33 feet at ordinary high-water; and though at present there is a sandbank at the outlet of the jetty-channel with a maximum depth of only 23½ feet over it at ordinary high-water, it is anticipated that a greater depth will be obtained over this bar, on the completion of the jetties, owing to the expected increase in the scour. The advance, however, of the sandy foreshore to the north-east of this outlet under the influence of the prevailing north-easterly winds, which has been rendered more rapid by the projection of the north-east jetty, may in the future occasion a diminution in the depth in front of the outlet obtained by the works, and necessitate dredging for maintaining it.

Protection of the Sea-coast bordering the Venetian Lagoon.—The works for defending the narrow fringe of coast bordering the lagoon from the attacks of the waves, forming the only barrier separating the lagoon from the Adriatic, extend along a total length of 12¾ miles, divided into four portions by the three outlets. The short length of 1,100 yards of shore-protection to the north-east of the Lido outlet is no longer required, on account of the stretch of sandy beach which has accumulated between it and the sea, owing to the south-westerly littoral drift of the alluvium brought down by the rivers Piave and Sile by the action of the prevailing north-east winds. This accretion, which is still discernible for some distance to the south of the Lido outlet, eventually disappears on the exposed stretch of coast leading towards Malamocco, along which protective works have been carried out for a length of 6,665 yards, against which the waves dash, especially during south-easterly gales; but accretion again occurs under the shelter of the Malamocco jetties (Fig. 1, Plate 9). The general nature of the defensive works along this part of the coast is shown in G, Figs. 8, Plate 9, except that, in the less exposed parts, rubble stone takes the place of the pitched slope, and is the most common arrangement for these works.[1] Protective works have been especially necessary along the very narrow belt of exposed coast

[1] "Ports Maritimes de l'Italie," pp. 274-275,

between the Malamocco and Chioggia outlets; so that, though sheltered for a short distance by the southern Malamocco jetty, the defensive works practically extend along all its length of about $7\frac{1}{2}$ miles. The systems adopted in the most exposed parts, and where the ground behind is near, or at, the level of ordinary high-water, are shown in H and I, Figs. 8, Plate 9; and in the last case the sea-wall forms the only barrier between the sea and the lagoon. In some places groynes have been carried out in front of these embankments or sea-walls to collect the drifting sand. These protective works have also been extended from the southern point of the Chioggia outlet for 1,996 yards along the coast; but southward of this, accretion takes place from the drift of the alluvium from the rivers Brenta and Adige, under the action of the waves raised by south-easterly winds. The total cost of these works of protection has been estimated at £800,000; and the expenses of their maintenance amount to about £1,200 a year.

Genoa Harbour and Ports.

Genoa, the principal seaport of Italy, owed its rise in early times, like so many ancient ports, to its position on a small fairly sheltered bay with deep water and good anchorage close to the shore at the head of the Gulf of Genoa, especially in a country bordered by the practically tideless Mediterranean Sea, where the rivers flowing into it are shallow and narrow down to their outlets when draining small basins, and obstructed by a delta when coming down from mountain ranges and draining large basins, so that they are not accessible to sea-going vessels of large draught, and ports have therefore to be provided in sheltered situations on the sea-coast. As traffic develops at these places, and vessels increase in size and draught, the sheltered bay becomes inadequate in area and depth; and extensive works have to be carried out in the sea beyond the bay, and in deeper water, to increase the sheltered area and the accommodation of the port. This is, in general outline, the history of several Mediterranean ports, such as Marseilles, Genoa, Naples, and Alexandria.

Inner Harbour of Genoa, and Old Port.—The old harbour of Genoa is a semicircular bay, nearly a mile in diameter, with hills rising near the shore to the north, sheltered on the west side by Cape Faro, and on the east by the coast of Sarzana; and the depth reaches $6\frac{1}{2}$ fathoms at the entrance to this harbour, and exceeds 5 fathoms over most of the harbour, and is little affected by the tide which only rises 1 foot, though under the influence of strong winds and changes in atmospheric

pressure the sea occasionally may be 2 feet above or below its mean level. The prevailing winds are from the south-east, and the strongest from the south-west, to the first of which quarters the bay was most open; whilst the worst seas come from about south-south-west, in which direction the fetch to the African coast is about 600 sea-miles. The Old breakwater, now serving as a jetty with quays, was gradually extended out from the south-eastern extremity of the bay, in a westerly direction, at intervals between the years 1283 and 1563, to protect the bay from south-easterly storms; and a basin was also commenced in 1283 alongside the north-eastern shore of the bay for a naval station, approximately on the site of the present basin; and the commercial port was situated between the basin and the Old breakwater which sheltered this part of the bay[1] (Fig. 9, Plate 10). The tranquillity, however, of the sheltered portion of the bay was impaired by degrees by the extension of the town on to stretches of sloping beach bordering the harbour, on which the waves originally expended their force; and, consequently, the New breakwater was commenced in 1634, starting near the south-western end of the bay and running in an east-south-easterly direction, for protecting the harbour from the worst waves coming in from south-south-west. Nevertheless, though the shelter of the harbour was improved by this incomplete breakwater, it remained sufficiently exposed for severe storms to injure the port and the shipping in the harbour, till both breakwaters were prolonged in 1846-68; but by this time the trade of the port had outgrown the accommodation.

Extension of Genoa Harbour.—Breakwaters were carried out in 1877-88 for forming an outer harbour beyond the limits of the bay, which, with the construction of jetties, quays, and graving-docks, the diversion of sewers from the harbour and improvements in the equipment of the port during the same period, and additional works since 1897 for increasing the accommodation, have brought the harbour and port to its present position.

The principal work carried out for the extension of the harbour is the Galliera breakwater, commencing near the outer end of the New, or western breakwater, and after proceeding nearly due south for 2,156 feet, turning round to an east-south-easterly direction for a length of 2,766 feet, thereby fully protecting the water-area between the breakwater and the south-eastern shore from south-westerly seas. The Giano breakwater was at the same time carried out from the south-eastern shore in a west-south-west direction

[1] "Ports Maritimes de l'Italie," pp. 23–61.

for a distance of 1,952 feet, well within the shelter of the Galliera breakwater from the south-south-west, so that vessels entering the outer harbour are protected by the Galliera breakwater from the worst waves before reaching the actual entrance, between the pier-head of the Giano breakwater and the Galliera breakwater, which is exposed to storms from south-east to about east-south-east. A return-portion was also added at the end of the New breakwater to increase the shelter in the inner harbour; and the concrete blocks protecting the upper part of the outer slope of the rubble mound were arranged as spurs projecting 10 feet, so as to break the waves and check the swell tending to enter the inner harbour.

The Galliera breakwater, situated in depths increasing regularly from 49 feet to 73 feet, consists mainly of a sorted rubble mound, protected on the lower portion of the sea-slope by large rubble, 5 tons to 50 tons in weight, and on the upper part by concrete blocks laid in stepped-back courses; and it is surmounted by a masonry superstructure, with a quay along the inner side sheltered by a high parapet-wall having a thick masonry apron extending in front of it on the sea side, protecting both the outer toe of the wall and the top of the rubble mound (Fig. 14, Plate 10). The rubble mound settled one-tenth of its height under the weight of the superstructure; whilst the subsequent settlement, resulting from the waves and the wear of the materials, has been slight and uniform. This breakwater occupied 11 years (1877-88) in construction; and its original cost was £654,600, or £133 per lineal foot. An exceptionally severe south-westerly storm on 27th November, 1898, produced a breach in the parapet-wall of the outer portion, 720 feet in width; the protecting concrete blocks were removed in places to a depth of 6½ feet to 20 feet; and the apron was destroyed near the angle of the two arms. In repairing this damage, the interval which had previously been left on the top of the rubble mound between the narrow apron and the courses of concrete blocks, was filled in by a thick, continuous apron covering the top of the mound and the top courses on the sea side, and protecting the parapet-wall up to more than half its height, as shown by the section of the reconstructed outer breakwater in Fig. 14, Plate 10. The New breakwater, which is 2,950 feet long, was also damaged by the same storm along the 820 feet constituting its outer, deepest portion, by the drawing down of the large rubble and concrete blocks protecting its mound below water, and the partial destruction of the apron. The cost of the repairs and strengthening of the Galliera breakwater amounted to about £32,000, and of the New breakwater £3,770.

The Giano breakwater, extending out into a depth of 52 feet, is

very similar in general construction to the Galliera breakwater in its original form, but considerably smaller and slighter, owing to its much smaller depth and less exposure (Fig. 13, Plate 10). This breakwater was carried out in 1883-88; and its cost was £84,000, or £43 per lineal foot.

The inner harbour has a water-area of 234 acres, with depths of 26 feet to 43 feet, but for the most part not less than 30 feet; whilst the outer harbour, enclosed by the Old, Giano, and Galliera breakwaters, has an area of 247 acres, with depths of 30 feet to 65 feet. The ample depths which now prevail throughout the harbour have been obtained by the aid of dredging with bucket dredgers, and preliminary blasting of rock where necessary, from 1877 to 1904, at a cost of over £179,200; and at the present time a small area in the angle of the outer harbour between the Old breakwater and Boccardo quay, in which the depth is under 5 fathoms, is being deepened to that extent, in a bottom of schistous limestone, by blasting and removing the fragments by a movable caisson under compressed air.

Extension of Jetties, Quays, and Graving-Docks.—During the extension of the harbour, numerous jetties were built out from the shore round the inner harbour, which have been equipped with sidings, cranes, and sheds (Fig. 9, Plate 10). The quay-walls lining these jetties are somewhat varied in type, as shown by their cross sections (Figs. 10 to 12, Plate 10); but they all rest upon a rubble base, and for the most part are backed up also with rubble. The type given in Fig. 10 is simply an improvement of the design of the older quay-walls along the shore, formed with courses of concrete blocks deposited under water, and its extension to deeper water, a system which has proved quite satisfactory, except on a high rubble base or a silty foundation; and this quay-wall cost £13 7*s.* per lineal foot. The quay-wall of the jetty enclosing the basin leading to the graving-docks under the shelter of the Giano breakwater, is shown in Fig. 11, Plate 10, and consists of a masonry monolith from the top of the rubble base to the water-level, constructed by aid of compressed air in movable caissons. The quay-wall to be built in the enlargement of the Caracciolo jetty, indicated by dotted lines on the plan (Fig. 9, Plate 10), is a combination of the above two systems; for it is to be constructed as a masonry monolith in movable caissons under compressed air for a height of 16¾ feet above the rubble base, and then raised to the water-level by concrete blocks to expedite the work and also cheapen it (Fig. 12, Plate 10). This jetty, the construction of which will necessitate the removal of the jetty projecting from the centre of the New breakwater, will afford a depth of 29½ feet in front of the quay-walls.

The quay-walls along the shore in the outer harbour, between the Old jetty and the graving-docks, being exposed to swell during south and south-easterly winds, have been built with masonry piers founded on rock by compressed air, placed at intervals apart with hollow spaces between, into which the swell can enter and spend its force against a rubble slope inside, instead of being reflected from a continuous quay-wall. The Grazie quay, which was exposed to the swell before the basin in front of it was enclosed by the projecting jetty, spans the intervals between the piers of 39½ feet by brick arches just above the water-level, built on iron centres suspended from above; but at the Boccardo quay, in a position of greater exposure between the Grazie quay and the Old jetty, lintels of ferro-concrete have been used in place of arches for spanning the spaces, 37¾ feet in width, between the piers, so as to reduce the surface of the face exposed to the waves to a minimum. The cost of the latter quay, with the spaces running back 26¼ feet, including the rubble slope inside, was £24 6*s*. per lineal foot.

Two graving-docks have been constructed under the shelter of the Giano breakwater, with lengths at coping-level of 588 feet and 721 feet, and along the blocks of 525 feet and 656 feet; widths at coping-level of 96 feet and 81 feet, and in the entrance at sea-level of 82 feet and 59 feet; and depths over the sill of 31 feet and 28 feet respectively. They are closed by ship-caissons; and the longer graving-dock can be divided into two docks by an intermediate caisson, with lengths of either 295 feet and 361 feet, or 426 feet and 230 feet. The cost of these graving-docks, with the approach-basin and accessory works, amounted to £355,650.

Expenses of Extensions, Equipment, and Various Works.—The works carried out by the Government between 1877 and 1904, for the extension and improvement of the Port of Genoa, have altogether cost about £2,359,700, of which the largest items, besides those of breakwaters, graving-docks, and dredging already given, are for quays and jetties, £658,560; warehouses and sheds, £134,880; hydraulic machinery, £105,700; custom-house and contingent works, £47,970; and sewers, £24,090.[1]

Commercial Progress of Genoa.—In 1874, when the commerce of the recently-established kingdom of Italy settled down to normal conditions, the total traffic of the port of Genoa was 700,569 tons of goods; and this traffic has increased rapidly since 1881, with only occasional fluctuations in years of abnormal trade, at the average rate of about 175,000 tons of merchandise per annum, so that it reached

[1] "Ports Maritimes de l'Italie," p. 54.

5,652,158 tons in 1903, raising Genoa to the position of the fifth port of the Continent of Europe. Of the above total, 4,891,417 tons consist of imports, or 86 per cent. of the whole; and slightly more than half this weight of imports was coals. In 1874 three-fourths of the vessels entering Genoa harbour were sailing-vessels; but the change to steamers in the case of many of these, so that sailing-vessels are now little more than one-third of the whole, has produced a drop in the number of vessels from 7,336 in 1874 to 6,335 in 1903, accompanied by an increase in the average tonnage from 212 tons to 906 tons.

The rapid growth of the traffic of the port has already outstripped the accommodation, consisting of 27,230 lineal feet of quays available for the loading and unloading of vessels, so that the inner harbour is encumbered with vessels waiting to discharge their cargoes. Accordingly, large extension-works have been designed, which were inaugurated by the King of Italy in October 1905.

Extension-Works authorized and in progress at the Port of Genoa.—The works already authorized comprise the extension of quays and railway-sidings in the existing port, a prolongation of the Galliera breakwater to improve the shelter in the outer harbour, and the construction of a breakwater from the angle of the Galliera breakwater running in a direction slightly north of west, approximately parallel to the New breakwater and the shore-line to the west of the bay, so as to shelter a basin to the south of the New breakwater, and provide for future extensions on the same principle as adopted for many years past at Marseilles, the works being indicated by thick dotted lines on the plan of the harbour[1] (Fig. 9, Plate 10).

The small Caracciolo jetty is to be enlarged to a length of 1,180 feet and a width of 410 feet, so as to be available for the coal traffic, and leave the adjacent Assereto jetty more fr e for a varied trade; and the Boccardo quay is to be completed, and a quay formed in continuation on the south side of the Old breakwater or jetty. Railway-sidings are to be provided along the quay to the north of the Assereto jetty, the Grazie, Boccardo, and extension quays, the quays of the new basin to the south of the New breakwater, and on the reconstructed Caracciolo and Old jetties.

The prolongation of the Galliera breakwater for 656 feet is designed to reduce the swell entering the outer harbour, especially during south-south-easterly storms, by more thoroughly overlapping the Giano breakwater from this quarter.

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[1] "Porto di Genova. Projetto di Ampliamento e Sistemazione approvato del Consorzio Autonomo," L'Ispettore del Genio Civile, I. Inglese, 1905.

The new outer breakwater will practically constitute a westerly extension almost in a line with the outer arm of the Galliera breakwater, and will hide the awkward bend of the inner arm by converting it into the eastern quay of the new Victor Emanuel III Basin, which will have an area of 96¼ acres with a depth of 6½ fathoms, and will provide 4,430 lineal feet of quay available for vessels. The eastern side of the basin is to be closed by a wide embankment for quays projecting out beyond Cape Faro, and a jetty carried out from the protecting breakwater, between which an entrance to the basin is to be left, 328 feet wide, which will be sheltered by the extension of the protecting breakwater about 2,200 feet west of it, making the total length of the breakwater, as at present authorized, 5,580 feet. Another entrance of the same width is to be formed on the opposite side of the basin, by cutting the opening for it through the inner arm of the Galliera breakwater; and it will be amply sheltered by the outer arm of the Galliera breakwater. The cost of these authorized works, which are designed to provide for the needs of the trade of the port for the next twenty years, is estimated at £2,000,000.

Provision has been made for future extensions in designing the present works; for it will be only necessary to continue the protecting breakwater in the same westerly direction parallel to the coast-line, and to carry out an embankment to it from the shore, in order to enclose a very large additional water-area, as shown by faint dotted lines on the plan (Fig. 9, Plate 10); whilst ample quays can be constructed alongside this extension, by reclaiming the foreshore along the coast to the north.

Spezia Harbour and Ports.

The harbour of Spezia, situated in a deep north-eastern embayment at the head of the Gulf of Spezia, is on a much grander scale than the old harbour of Genoa (compare Figs. 9 and 15, Plate 10), and is very well sheltered by the projecting coast and islands, on its western and south-western sides, from the prevalent and stormy south-westerly winds, which raise the worst seas on that coast; so that it was only exposed to south-easterly winds, from which it has been protected by a breakwater, submerged except at the two extremities, stretching across the opening of the bay, and leaving only narrow entrances at the two ends between the pierheads and the coast. The breakwater was constructed solely for naval objects; but it is of great benefit in sheltering the commercial port, which occupies a site more exposed in its natural condition than the arsenal and its basins, which constitute

the principal naval station in Italy. Spezia harbour presents a considerable resemblance to Plymouth harbour, both in its general form and method of protection; and, like Plymouth, it affords sheltered access and ample anchorage, with good holding ground, to a very important naval arsenal, and to a small commercial port. Spezia does not possess the same excellent central position for railway communication as Genoa; and the propinquity of a naval station tends to check commercial development; but as regards shelter and space for extensions, Spezia has much greater natural advantages than Genoa.

Naval Port of Spezia.—The arsenal occupies a very well-sheltered recess on the north-west side of the bay, where deep water comes close inshore, so that both the basins and their approach-channels possess depths of 5 to 6 fathoms, with similar depths across the harbour in front, increasing towards the south-east to 6½ and 7 fathoms inside the harbour, and greater depths in the gulf outside [1] (Fig. 15, Plate 10). Besides two large basins, the naval port possesses some smaller basins, building-slips, fitting- and repairing-shops, and all the appliances for the construction and equipment of warships, several graving-docks, coal-sheds and coaling-jetties, railway-sidings, electric-light installations, and everything necessary for a first-class naval port. A large experimental tank of considerable length has also been constructed, with elaborate measuring-apparatus, along which models of the hulls of vessels moulded in paraffin, are drawn through water to ascertain the best forms for speed, and trials of different forms of models of screw-propellers are conducted.

Commercial Port of Spezia.—The commercial port adjoins the naval port on the north-eastern side, and extends along the coast to the northern extremity of the bay, on a comparatively shallow site where the depths ranged for the most part between 2 and 3¾ fathoms. Up to the construction of the naval arsenal and the drainage of the extensive marshes bordering the eastern shore of the bay, carried out during the latter half of last century, a very small trade was conducted alongside some old quays which constituted the port in this sparsely populated and unhealthy district; but the works, and the opening of the railway from Parma to Spezia, produced a rapid increase of the population, and, consequently, in the commerce of the port. Two small jetties and some quays along the shore near the naval arsenal were accordingly constructed to improve the shelter of a small basin, and extend the accommodation for vessels.

[1] "Gulf of Spezia," Admiralty Chart, London.

Works subsequently carried out to the north-east of the previous works, between 1890 and 1900, at a cost of £140,000, have extended the port to its present state (Fig. 15, Plate 10).

The old commercial port of Spezia, adjoining the naval arsenal, consists of a little basin of 5 acres, which will soon be taken over by the arsenal, and 3,740 feet of sheltered quays extending to the battery. The new port, formed in 1890-1900, comprises a water-area of 50 acres, protected by a breakwater, or jetty, extending out at right-angles to the northern shore of the bay for a length of 1,312 feet, with a quay-wall along its sheltered western side for 984 feet, and a quay along the adjacent northern shore to the west, 656 feet long; and the sheltered area has been gradually deepened to 26¼ feet by dredging in the silty bed of the harbour. The inner portion of the projecting jetty has been given a width of 177¾ feet, so as to provide sufficient space for three lines of railway, a wagon-road, and a coal-depot; and the quay-wall alongside the sheltered area had been constructed of concrete blocks deposited under water on a rubble mound, with a small masonry wall on the top, affording a depth of about 23 feet in front; whilst the eastern side of the jetty consists of a rubble mound raised to sea-level, having a small retaining-wall on the top to keep back and protect the earthen embankment of which the jetty is mainly composed[1] (Fig. 16, Plate 10). The outer portion of the jetty is composed of a rubble mound raised 6½ feet above sea-level; and it has been made 330 feet longer than originally designed, in order to protect the sheltered area better from the littoral drift of silt from the eastern shore of the gulf.

Growth of Commerce at Spezia.—The total goods-traffic of the commercial port of Spezia, which was only 109,300 tons in 1894, rose to 200,000 tons in 1899 when the extension-works had become available, and reached 345,000 tons in 1904, of which about 310,000 tons were imports, coals alone amounting to 205,000 tons. Sailing-vessels trading with this port have remained up to the present more numerous than steamers, numbering 1,151 in 1904 out of a total of 1,955.

Extensions authorized and proposed at the Commercial Port of Spezia.—An extension of the port was authorized in 1904 to provide for the rapidly increasing traffic. The chief works consist of the prolongation of the north breakwater, or jetty, in a south-westerly direction, at an angle to its original southern course, for a length of 330 feet, to improve the shelter; the transformation of a length of 656 feet of the outer protecting rubble mound into a jetty; and the provision of

[1] "Ports Maritimes de l'Italie," pp. 64–69.

additional sidings, electric cranes, and sheds. Quay-walls are to be built on both sides of the prolongation of the jetty, as it has been found that the sea is calm enough for a great part of the year on the eastern side for the loading and discharging of vessels; and these quay-walls are to be constructed in a similar manner to the quay-wall of the inner jetty (Fig. 16, Plate 10), providing a depth in front of them of 28 feet on the side of the port and 19⅓ feet on the outer eastern side, and giving a width of jetty of 216½ feet. The extension of the mound beyond the jetty is to be effected by a rubble mound up to sea-level, surmounted by a row of rubble masonry blocks, 13 feet wide and 6½ feet high.

In anticipation that even these new works will soon become inadequate for the growing traffic, further works have been proposed, sufficient to supply the needs of the estimated traffic for the next twenty years at least. The scheme thus drawn up comprises the formation of a little basin for sailing-vessels on the north-east side of the battery; a further prolongation of the south-western branch of the protecting mound beyond the jetty for 1,150 feet, with an inner quay-wall; the construction of a new quay from the eastern end of the north quay to the new basin; the formation of a wide embankment for quays along the northern shore for about 1,300 feet to the east of the jetty, with a quay-wall accessible by sailing-vessels; and the equipment of these new quays. These proposed works would increase the length of quays available for commercial operations to a total of 6,560 feet.

Naples Harbour and Ports.

The ports of Naples, both naval and commercial, are situated at the northern extremity of the magnificent Bay of Naples, bounded by Gaiola Point on the west and Torre del Greco on the east; whilst the gulf extends out to the open sea between the islands of Ischia and Capri, being somewhat sheltered from the west-south-west by the islands of Ischia and Procida, and by the island of Capri from the south, and fully protected by the mainland from Cape Miseno at the west round by north to Cape Campanella at the south-east, as shown by the little map (Fig. 17, Plate 10). The gulf and bay, however, are fully exposed to south-westerly winds, which are the prevalent and strongest winds during the winter all along the Tyrrhenian coast, and have a fetch in this locality of 300 sea-miles to the African coast; and though the bay is considerably sheltered from south-easterly storms by the peninsula of Sorrento, nevertheless, the seas rushing through

the opening between Cape Campanella and the island of Capri, and being propagated by the wind during south-easterly gales through the wide entrance to the harbour, produce a considerable motion inside, the worst winds in this respect being east-south-east, in spite of the apparent fair protection from this quarter.

The Bay of Naples was under less favourable natural conditions for the formation of a small harbour, sufficient for the wants of early days, than the Gulf of Genoa; but it is decidedly better suited, both in form and extent, for the large extensions necessitated at the present time by the increase of traffic, than Genoa, and even in some respects than Spezia, though requiring more artificial shelter than that land-locked bay (compare Figs. 9, 15, and 18, Plate 10). The ordinary rise of tide at Naples is about 1 foot 4 inches; but under certain conditions of wind and atmospheric pressure, the sea-level may vary to the extent of 2 feet 9½ inches.

Origin of Naples Harbour.—In ancient times there appears to have been a creek to the north of the Old port, which provided shelter for the small vessels of that remote period, but was gradually silted up; and the first work for forming a harbour was the construction of a breakwater, undertaken in 1302, on the site of the existing Angioino breakwater on the south side of the Old port, which was destroyed by a storm in 1343, and whose reconstruction was commenced in 1447, and a short northern arm added later on; whilst further accommodation was provided in 1668, by the formation of a basin to the south of the Castel Nuovo. The Old port being still exposed to south-easterly storms, the San Gennaro breakwater was built out in prolongation of the short northern arm in 1743[1] (Fig. 18, Plate 10).

Enlargement of the Harbour of Naples.—Up to 1836, the only shelter provided for shipping consisted of the old commercial port, and the little basin to the south of the Castel Nuovo, now forming part of the naval port; but at this period the principal protective work, known as the San Vincenzo breakwater, sheltering the harbour from south-westerly storms, was commenced, extending from the western shore of the bay in a direction slightly south of east, for a length in the first instance of 1,800 feet, under the shelter of which the present naval port was formed. In 1862, soon after Naples had come under Italian rule, extensive enlargements were approved, which, carried out by degrees up to the present time, though with some important modifications, have formed the existing harbour. The works comprised the prolongation of San Vincenzo breakwater, the construction of an eastern breakwater stretching out from the north

[1] "Ports Maritimes de l'Italie," pp. 110-137.

hore in a southerly direction far enough towards the San Vincenzo breakwater to reduce the opening between them to 1,312 feet facing east, and the construction of basins, jetties, quays, and graving-docks for the new port. In 1880, a further prolongation of the San Vincenzo breakwater was decided upon, and also the formation of a new commercial port by the projection from the end of the Eastern breakwater of the two canted Martello and curved arms, the building of quays along the shore to the west and south-west of the Eastern breakwater, the general deepening of the sheltered areas, and the connection of the port with the railway. The curved breakwater, however, would have left an opening between its pierhead and the San Vincenzo breakwater of 1,800 feet, facing slightly south of east, through which sufficient swell was likely to enter to disturb unduly the tranquillity of the harbour. Accordingly, in 1900, the construction of a detached outer curved breakwater was authorized, turning the entrance of the harbour so as to face due south, and reducing its width to 984 feet (Fig. 18, Plate 10).

Description of the Harbour of Naples, and its Ports.—The outer harbour, enclosed by the San Vincenzo, Gennaro, Martello, and curved breakwaters, has an area of about 136 acres, having depths of from $5\frac{1}{2}$ to $16\frac{1}{2}$ fathoms; the naval port, bounded by the Angioino breakwater, the quay in front of the Castel Nuovo, and the inner part of the San Vincenzo breakwater, is $22\frac{1}{4}$ acres in extent, and has depths of $2\frac{3}{4}$ to $6\frac{1}{2}$ fathoms; and the commercial port, comprising the Old and New ports and the basin leading to the graving-docks to the east of the Eastern breakwater, has a total water-area of 84 acres, with depths of $2\frac{1}{4}$ to 5 fathoms in the Old port, $4\frac{3}{8}$ to 6 fathoms in the New port, and $5\frac{3}{4}$ fathoms in the graving-docks basin. In the existing state of the works, only the most violent south-westerly storms affect the water in the harbour; but ordinary south-easterly storms disturb the water in every part of the harbour, except the graving-docks basin; and great storms produce an inconvenient swell in the most remote parts of the harbour, and even in many parts of the inner basins, endangering the safety of the vessels. It is anticipated that the completion of the curved, detached outer breakwater will stop this disturbance, especially if the original design is reverted to of limiting the width of the entrance to 984 feet and making it face south by a prolongation of the detached breakwater 197 feet, as shown by dotted lines (Fig. 18, Plate 10), instead of the present plan of leaving the entrance 1,150 feet in width and facing slightly east of south.

The naval port is surrounded by quays, and, together with a portion of the harbour in front of it, the old basin, and the little graving-

dock alongside the San Vincenzo breakwater, is exclusively reserved for the requirements of the royal navy; and an arsenal, with numerous workshops and stores, has been established round it.

The commercial port possesses 12,025 lineal feet of quay-walls bordering the jetties and shore, of which, however, only 4,530 feet are available for large vessels; and the extent of accessible quays is generally so inadequate for the number of vessels frequenting the harbour, that vessels have constantly to discharge and take in their cargoes by means of lighters. Most of the quay-walls have been built, below sea-level, with concrete blocks laid directly on the sea-bed or on a rubble foundation, though in a few instances concrete-in-mass deposited within wooden frames had been adopted. For the new quay-walls, however, in progress round the graving-docks basin, and at the enlargement of the trapezoidal jetty, masonry built under compressed air in movable caissons has been employed. The largest graving-dock is 690 feet long, and has a depth of water of 33¾ feet over its entrance sill.

Breakwaters protecting the Harbour of Naples.—As in the case of Genoa harbour, the early protecting breakwaters at Naples harbour, being converted into interior works by the later extensions, have been turned into jetties with quays, such as the Angioino and San Gennaro breakwaters. The inner curved breakwater, originally designed to form the eastern protection of the harbour in continuation of the Eastern breakwater, and constructed, like most of the recent Italian breakwaters, of a sorted rubble mound, surmounted at about sea-level by a superstructure with a quay and sheltering parapet-wall, and protected on the sea slope by large rubble below and large concrete blocks in courses on the upper part to above sea-level (Fig. 19, Plate 10), has now, owing to changes in the mode of protecting the harbour dictated by experience, ceased to be of service, and has, indeed, been cut away from the Eastern breakwater to provide an entrance to the graving-docks basin, a work which has necessitated the construction of a small breakwater to the east of the Eastern breakwater for enclosing and sheltering the basin. Moreover, the shallower Martello breakwater of similar construction, though still useful in protecting the new commercial port from south-easterly storms, should, if the anticipations of the shelter provided by the detached outer breakwater are realized, soon cease to be required for protection.

Accordingly, the breakwaters which in future will alone serve to protect the harbour of Naples are the Vincenzo breakwater, the most important, both on account of its length and its direct exposure to the worst seas, the outer detached breakwater, and to a minor extent

the graving-docks basin breakwater, together with any easterly extension of the outer breakwater that may hereafter be carried out.

The Vincenzo breakwater was built out from the shore between 1836 and 1883, for a distance of 3,800 feet, as a simple rubble mound, surmounted by a superstructure of masonry forming a quay, though it was given a stronger form after being injured by storms in 1866, 1872, and 1879, mainly by concrete blocks deposited at random on the outer slope, and a triple row of masonry blocks at the top of the mound on the sea side of the parapet-wall. Along a length, however, of 1,115 feet the outer protection of concrete blocks was overlaid with rubble, for fear that any break in continuity of the protecting blocks, due to scour of the waves, settlement of the mound or other cause, might result in serious damage; but experience has proved that this precaution has not prevented the constant displacement of blocks, and the formation of breaches in the superstructure nearly every year; and it appears that the remedy adopted has tended to lead up the waves to the superstructure, with a corresponding dangerous recoil, instead of their being broken by the interstices between the blocks in their passage up and down the slope. The outer portion of the breakwater adjoining the pierhead has been strengthened, by reducing the stepping back of the courses of concrete blocks on the outer slope, the provision of a masonry apron in front of the parapet-wall, and the omission of the covering of rubble (Fig. 20, Plate 10); and this part of the breakwater, though situated in the deepest water, has remained intact since its completion about 7 years ago. The breakwater is 4,920 feet long, and the outer portion, beyond the inner 1,804 feet belonging to the naval port, cost about £520,000, averaging between £121 and £242 per lineal foot according to the depth, which increases from about 5½ fathoms near the shore-end up to 19 fathoms at the pierhead. The cost of maintenance of the outer 3,116 feet is about £2000 annually, mostly expended on repairs of the length of 1,115 feet referred to above.

The outer, detached breakwater, in course of construction, is the only other breakwater of importance in the Naples harbour-works; and though it only protects the harbour from south-easterly winds with a moderate fetch, storms from this quarter have produced considerable disturbance in the harbour. Moreover, it is situated in depths increasing from about 11 fathoms at the shallowest north-eastern end, to 17½ fathoms at the south-western pierhead; and it possesses the interest of being apparently the first large breakwater on the Italian coast which has been constructed according to the modern composite type, of a rubble mound surmounted by a super-

structure founded on the top of the mound at a sufficient depth below sea-level for the waves not to disturb the large stones covering the mound (Fig. 21, Plate 10). The breakwater is to have a length of 1,640 feet; and the superstructure increases in width, according to the exposure and depth, from 33 feet at 1⅓ foot above sea-level for the first 984 feet from the north-eastern end, to 42⅝ feet for the next 541 feet, and 74 feet for the remainder, serving as a pierhead and a site for a lighthouse at the most exposed south-western end. These widths are maintained below for 13 feet, or two courses of blocks, and then are stepped out 2 feet at each course of blocks on the sea face, and 1⅓ foot on the harbour face, the superstructure being formed up to sea-level of five courses of concrete blocks founded 31 feet below sea-level, except at the south-western pierhead which is founded at a depth of 37¾ feet, the outer blocks in each course being connected with the inner blocks by iron cramps. In view of the importance of keeping the superstructure perfectly compact, the rubble mound was carried out in lengths 2 years in advance of the superstructure, and was formed of rubble stones of all sizes to reduce the interstices to a minimum, so as to diminish its settlement as much as possible; and the superstructure had been laid on the mound in lengths consisting of one or two courses at a time, so as to avoid sudden and unequal settlement, and to enable the whole length to be levelled before laying the next course. The superstructure is capped above sea-level by solid masonry forming a quay, and a sheltering parapet-wall, as shown by Fig. 21, Plate 10, representing the outer length of 541 feet adjoining the pierhead. The estimated cost of this breakwater is rather over £120,000, or £72 12*s*. per lineal foot, considerably less than the cost of the outer 3,116 feet of the San Vincenzo breakwater built in a smaller average depth, which may be attributed, in addition to economy of modern appliances in construction, to the great reduction in materials effected by the modern composite type, as illustrated by a comparison of Figs. 20 and 21, Plate 10.

The much smaller breakwater protecting the graving-docks basin, in comparatively shallow water, has been built similar in type to the outer breakwater, with a superstructure founded on a rubble mound at a depth of 12½ feet below sea-level. It is 2,460 feet long, and cost £22,400.

Cost of the Extension- and Improvement-Works at the Harbour of Naples.—The works carried out by the Government at the commercial harbour of Naples from 1862 to the present time, including the works in progress, involve an expenditure of £1,404,000. The principal items of cost, in addition to the breakwaters already given, are the rearrangement of the Old commercial port, £52,000; the construction

and equipment of the New commercial port, £308,000; graving-docks and contingent works, £200,000; and buildings for the passenger and emigrant services, £29,000.

Commercial Development of Naples Harbour.—The commerce of the port of Naples has been advancing during the last twenty years at a continually increasing rate, with the exception of a short period of depression after 1890; for the traffic has grown from 741,760 tons of merchandise in 1885 to 893,216 tons in 1895, and up to 1,205,366 tons in 1903, of which 933,132 tons were imports and 272,234 tons were exports, coals again appearing as one of the principal imports. The increase, however, of the shipping has been still more rapid, owing to the remarkable development of the passenger and emigrant traffic, Naples having become a port of call since the opening of the Suez Canal, and the first port in Italy for passenger and postal service, as well as the chief port for the embarkation of emigrants. Thus in 1885 about 8,000 vessels, registering 3,500,000 tons, entered and cleared from the port of Naples; in 1895, 12,011 vessels, of 5,054,055 tons total tonnage; and in 1893, 12,591 vessels, consisting of 6,331 steamers and 6,260 sailing-vessels, of 9,186,779 tons total tonnage.

Extension-Works proposed for the Port of Naples.—Even when the works in progress at the graving-docks basin shall have been completed, the length of quays accessible by large merchant-vessels at the commercial port of Naples will be only 6,890 feet, which will be inadequate to accommodate the rapidly growing traffic. Accordingly, the expenditure of £500,000 was authorized in 1904 on an extension of the port of Naples along the Granili shore, to the east of the present port. This extension is to consist of a large water-area to be sheltered by a breakwater starting from the inner extremity of the outer breakwater, and running in a south-easterly direction, parallel to the shore, for a length of 3,280 feet, in which area three wharves are to be carried out from the shore, each 984 feet long and 394 feet broad, leaving spaces of water between them 394 feet in width, as shown by dotted lines in Fig. 18, Plate 10; and these wharves are to be surrounded by quay-walls affording a depth of 33 feet of water in front of them, capable of accommodating eighteen vessels at the same time, and fully equipped for the handling of cargoes. By this addition the commercial port will be enabled to deal with a traffic attaining 2½ million tons of merchandise in a year.

Concluding Remarks.

The basin of the River Po is a very interesting instance, in which, having trusted hitherto to the facilities of navigation afforded by nature, and having neglected all works of improvement beyond the mitigation of floods by embanking the river, whilst the system of communication by means of light railways has been very extensively developed, it has at length been decided to improve and extend inland navigation throughout the whole of the Lombardy and Venetian plains according to a comprehensive scheme, adapting the enlargement of the waterways to the requirements of the districts and the possibilities offered by nature at a reasonable cost, and completing the intercommunication of the inland waterways, and access to important centres of commerce and isolated lakes, by the construction of canals.

The port of Venice affords a remarkable instance of a lagoon harbour whose preservation from being silted up by the alluvium carried into it by rivers, and from inroads of the sea, has been carefully guarded from remote periods by extensive works; and it has been gradually adapted to the increasing requirements of shipping and a growing commerce; and the improvement of its deep-water access to the sea is still in progress, as well as further extensions of the port.

Italy having only tideless rivers impeded by their alluvium, but a very extensive sea-coast, is dependent on its harbours for its maritime commerce; whilst the natural harbours are few in number, or of inadequate size, and require to have their shelter improved, or their area increased, by artificial means. The three most important commercial harbours have been described in the Paper, namely, Genoa, Venice, and Naples, whose improvement and extension have necessitated very extensive maritime works, as well as the provision of quays, jetties, and other facilities for trade; whereas Spezia, the fourth harbour described, one of the best natural harbours of Italy, has required a breakwater at its entrance to complete its shelter, and is the most important naval station of the kingdom.

The breakwaters constructed for the extension of the harbours of Genoa and Naples have, with one exception, followed hitherto the type usually adopted for Mediterranean harbours, namely, a rubble mound with a superstructure founded at sea-level, with a quay on the inside sheltered by a parapet-wall, and protected on the sea side, and partly down the outer slope of the mound, by large concrete blocks (Plate 10), of which the Marseilles breakwater is a notable example. The only

change introduced by Italian engineers, for several years past, has been the laying of the concrete blocks in courses stepped back on the sea-slope, and, more recently, leaving narrow spaces between the rows of blocks protecting the top of the mound, instead of depositing the blocks at random. The outer breakwater, however, in progress at Naples, is being built in accordance with the more modern type of composite breakwater in deep water, introduced probably for the first time at Alderney, after the early injuries at that very exposed site, more than fifty years ago, in which type the superstructure is founded on the rubble mound at a depth at which it is anticipated that the waves will not disturb the mound, as adopted by British engineers at Karachi, Madras, Colombo, Mormugao, and other harbours, in place of the old system of a superstructure founded at low-water level on the mound, of which Holyhead, Portland, and Cherbourg breakwaters furnish notable examples. The difficulty is to determine the level below low-water or sea-level at which the mound is not liable to be disturbed by the waves; and this depth, depending upon the exposure and the depth of water in front of the breakwater, has had to be increased, from the results of experience, as pointed out by the Author in his Paper on "The most recent Works at some of the Principal British Seaports and Harbours" for the Paris Navigation Congress of 1900, from 12 feet below low-water, as first adopted at Alderney—which proved quite inadequate there—down to 30¾ feet at the Colombo north-west breakwater, and 43 feet below low-water at Peterhead.[1] The adherence to the old type of composite breakwater so long by Italian engineers has probably been due to the less exposure, and, consequently, smaller waves in the Mediterranean as compared with those experienced at the other harbours mentioned above, notably Alderney, Madras, Colombo, and Peterhead. As, however, the change in construction introduced at the outer breakwater at Naples, besides being calculated to diminish materially the cost of maintenance by avoiding the breaking of waves on a sloping mound, appears to be also considerably less costly than the old system followed at the San Vincenzo breakwater, probably the breakwater for sheltering the extensions commenced at Genoa harbour will be similarly constructed. Moreover, it should be noted that a quay on an outer sheltering breakwater is of no use for purposes of trade, and merely gives

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[1] Eighth International Congress on Navigation, Paris, 1900: 7th Question, "The most recent Works at some of the Principal British Seaports and Harbours," report by L. F. Vernon-Harcourt, p. 14; and Tenth Congress, Milan, 1905, Section II, Ocean Navigation: 4th Question, "Conditions affecting the Force of Waves and the Construction of Breakwaters to resist them," L. F. Vernon-Harcourt, p. 9.

access in fairly calm weather to a lighthouse at its extremity, which might be otherwise provided for; and therefore, in most cases, the protecting parapet-wall might be omitted with advantage, as it increases the shock of the waves against the breakwater during storms, and also their recoil, and, consequently, renders the breakwater more liable to injury.

The harbour-works described in the Paper, and the extensions in progress or proposed, and also the comprehensive scheme submitted for improving and extending inland navigation in North Italy, indicate very forcibly the solicitude displayed by the Italian Government to adopt every means in their power for promoting inland navigation, and the capabilities and safety of their harbours for maritime traffic, as being the surest method of developing the resources of their country and increasing its prosperity and progress.

The Paper is accompanied by two tracings, from which Plates 9 and 10 have been prepared.

OBITUARY.

HENRY WILLIAM BROCK, elder son of Mr. Walter Brock, the present head of the shipbuilding and engineering firms of Messrs. Denny and Brothers and Messrs. Denny and Company, Dumbarton, was born in Glasgow on the 15th March, 1869, and received his education at Dumbarton Academy and Fettes College, Edinburgh. On leaving college he served an apprenticeship with Messrs. Denny and Company, and with the Société Anonyme Forges et Chantiers de la Méditerranée, of Havre. After gaining further experience as a draughtsman in the Central Marine Engine Works, West Hartlepool, he became a partner in the engineering firm of Denny and Company in 1892, and in the shipbuilding firm of Denny and Brothers in 1896. From the outset of his career at Dumbarton, he threw himself with characteristic zeal and conspicuous ability into the responsible work which fell to his share. This comprised the design and erection of all the marine work turned out, including screw, paddle-, and stern-wheel machinery for ocean-, channel-, and river-steamers, averaging about 40,000 I.HP. annually, and the conduct of trial trips and scientific tests to determine the efficiency of various types of machinery. Mr. Brock was among the first to recognize the importance of the marine steam-turbine, and his firm were the first to be associated with the Parsons Marine Steam Turbine Company in the construction of turbine-vessels for the Clyde and for the English and Irish Channels, as well as for ocean service. The British India Company's steamship "Lunka" was built and fitted with turbine machinery, constructed at Dumbarton under Mr. Brock's direction, these turbines being probably the first to be built outside the Parsons establishment. Mr. Brock served on the committee appointed by the Cunard Company to investigate the suitability of turbine machinery for Atlantic liners, and took an active part in the work of the committee. By his untimely death on the 10th February, 1906, at the early age of 36, the profession lost an engineer of marked ability who had already attained a prominent rank, and whose career was full

of promise for the future. Mr. Brock was a Member of the Institution of Naval Architects and of other technical societies.

He was elected a Member of this Institution on the 19th April, 1904.

OSWALD BROWN, born in 1848, the son of the late Mr. Joseph Brown, C.B., K.C., was educated at King's College, London, and apprenticed in 1866 to Messrs. James Simpson and Company, of Pimlico, for whom, on completing his articles, he went to Berlin to assist in superintending the erection of pumping-machinery at the Berlin waterworks. Between 1868 and 1870 he acted as assistant engineer to the Servian Copper and Iron Company in Servia, and in the latter year, under the direction of Sir Charles Hartley, he superintended the erection of a lighthouse at Sulina for the Danube Commissioners. Subsequently he became Resident Engineer for the construction of the Galatz waterworks, and also designed similar works for Jassy, Bucharest, and Ibraila. After acting for a short period as Mechanical Engineer to the Royal Sardinian Railway Company, he proceeded in 1878 to Australia, to take up the appointment of Hydraulic Engineer to the South Australian Government. In this capacity he designed and successfully carried out, in the face of strong political opposition, a large and important water-supply scheme for Adelaide, the first of its kind in Australia. The results of four years' working completely justified the faith of the designer, bringing a large increase of revenue to the Government, and enabling a considerable reduction to be effected in the water-rate. In 1882 Mr. Brown resigned his appointment and left Australia. After carrying out certain works in the south of France, he engaged in independent practice in Westminster, his services being retained as Consulting Engineer by the South Australian Government. He designed the Pernambuco waterworks and was consulted with reference to many other schemes in all parts of the world. In 1891 he carried out an extension of the works which he had designed at Adelaide. He died at his residence at Wimbledon on the 10th February, 1906, aged 58. In the branch of engineering to which his career was devoted his abilities won due recognition; to his own modesty and reticence is largely due the fact that the good work which he did was not more widely known. Mr. Brown was a Member of the Institution of Mechanical Engineers.

He was elected an Associate of this Institution on the 3rd March, 1874, was subsequently placed in the class of Associate Members, and was transferred to the class of Members on the 25th May, 1880.

GEORGE WILLIAM CATT, died at his home in New York City, on the 8th October, 1905, aged 45. Born at Davenport, Iowa, on the 9th March, 1860, he received his preliminary education at the public schools and subsequently passed through the Iowa State College, graduating in 1882. On leaving college, he joined the staff of the King Bridge Company, of Cleveland, whom he represented as contracting engineer for several years in the Mississippi Valley and on the Pacific Coast. In 1887 he became Chief Engineer to the San Francisco Bridge Company, in which capacity he designed and erected a large number of bridges for railroads and municipalities. Whilst at Seattle, Washington, he rebuilt most of the piers and other water-front structures destroyed in the fire which occurred in 1889. In 1891 he obtained the contract for extensive hydraulic dredging operations in Boston harbour, which being successfully completed led to the foundation in the following year of the New York Dredging Company, of which Mr. Catt became President and Chief Engineer, his services being retained by the San Francisco Bridge Company as Consulting Engineer. During this period he designed and erected four large dredging-plants and executed a large amount of river- and harbour-improvement work, chiefly on the Pacific Coast. He also built the first modern drainage-station for New Orleans and a ship-canal, 7 miles in length, for the Port Arthur Channel and Dock Company, Texas, the construction of which necessitated the removal of 5 million cubic yards of material. In 1899 the New York Dredging Company was incorporated with the Atlantic, Gulf and Pacific Company, of which Mr. Catt became President and Chief Engineer, retaining this position until his death. Besides actively directing the extensive operations of his company in all parts of the United States, he acted as Consulting Engineer to the Puget Sound Bridge and Dredging Company, the San Francisco Bridge Company, and the British Columbia General Contract Company. In 1891 he succeeded in obtaining the contract for the improvement of Manila harbour, involving the rebuilding and extension of the Spanish jetties, the dredging of a large anchorage-basin to the depth of 30 feet, the construction of an additional breakwater and the building

of a rock bulkhead behind which the spoil of the dredging was deposited. Whilst the work was in progress Mr. Catt also built a large coaling-station, with full equipment, at Sangley Point, near Manila. One of the last important contracts which he undertook was the reclamation of salt marshes contiguous to Cape May, New Jersey, to allow of the extension of that town and district, work involving the dredging and depositing of 10 million cubic yards of material.

Mr. Catt was a Member of the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Academy of Political and Social Science, and the Franklin Institute of Philadelphia. By virtue of his rare abilities and high personal character he attained a prominent place in the ranks of the profession in America, and won the respect and esteem of all who came into contact with him.

Mr. Catt was elected a Member of this Institution on the 6th March, 1900.

WILLIAM HENRY ROBINSON CRABTREE, Borough Surveyor and Engineer of Doncaster, died on the 27th December, 1905, aged 48. The eldest son of the late Mr. William Crabtree, who was then Borough Surveyor of Southport, the subject of this notice was born at Ardwick, Manchester, on the 9th December, 1857, and received his engineering training under his father, between 1873 and 1876. On the expiration of his pupilage, he served as Assistant Engineer and subsequently as Resident Engineer on the main sewerage works and on the North Promenade extension, sea-wall and reclamation of 43 acres of foreshore at Southport. In 1880 he joined the staff of the late Mr. James Mansergh, Past-President, for whom he acted as Resident Engineer on sewerage works for Beckenham, Shortlands, Bethesda and Burton-on-Trent, and waterworks for Bethesda, Sherborne and Rotherham.

In 1887 Mr. Crabtree was selected for the appointment of Borough Surveyor and Engineer of Doncaster, a post which he retained until his death. During his tenure of this office, he designed and carried out amongst other works sewerage and water-supply extension works, new hospitals, schools, baths and other buildings, as well as various street improvements and, in conjunction with Mr. J. N. Shoolbred, the Corporation electric-light and power supply and tramway-system. He also laid down the pipe-line by which Doncaster is now supplied with water from Sheffield. In addition to the sufficiently onerous duties of his office, he also acted

in recent years as agent in charge of the Corporation estates. He was devoted to his duty, in the performance of which he spared no personal efforts, and his death was deeply regretted by the community which he served with unvarying zeal and ability.

Mr. Crabtree was elected an Associate Member of the Institution on the 29th May, 1883, and was transferred to the class of Members on the 18th December, 1900.

WILLIAM CUDWORTH was born at Darlington in 1815 and was educated privately. As a boy, he witnessed the opening, in September, 1825, of the Stockton and Darlington Railway, with the fortunes of which his future became largely identified. He was apprenticed to a shipbuilder in Sunderland, and obtained in the shipyard a thorough knowledge of carpentry and of wooden shipbuilding, which was supplemented by a short voyage as a sailor. Thus equipped, he commenced business as a shipbuilder in the then recently founded town of Middlesbrough, but gave this up in 1840 and entered the service of the Stockton and Darlington Railway Company under the late Mr. John Harris.

About 1850, when the Cleveland iron-mining district was being developed, he was appointed engineer for the construction of the Middlesbrough and Guisborough Railway, a feeder to the Stockton and Darlington line; and on the completion of this work he found full occupation in connection with a series of protracted parliamentary contests which arose out of the proposed further development of that district.

In 1857 and the following year, the construction of the Hownes Gill Viaduct on the Stockton and Darlington railway[1] occupied much of his attention, and about this time he succeeded Mr. John Dixon as engineer to that railway, retaining this position in the Darlington District after the amalgamation of the Stockton and Darlington with the North Eastern Railway. As Engineer to the Company, he carried out large groups of marshalling sidings at Shildon and Newport,[2] new passenger- and goods-stations on an extended scale, widenings, and other works necessitated by the exceptionally rapid development of the Middlesbrough District. About 1869 he took in hand the enlargement of Middlesbrough Dock, the late Mr. T. E. Harrison being Consulting Engineer.

[1] Minutes of Proceedings Inst. C.E., vol. xxii, p. 44.
[2] *Ibid*, vol. xli, p. 89.

This was new work to Mr. Cudworth, but his love for ships and shipping made it congenial.

In 1883, shortly after the death of his wife, he retired from professional life, and devoted the prolonged remainder of his days to works of philanthropy and to literature. Possessing a cultivated literary taste, he occupied himself in making translations into English verse of several of the masterpieces of Greek and Latin literature. When over 80 years of age he learned Italian in order to read Dante in the original. He died on the 4th June, 1906, in his ninety-first year. Mr. Cudworth was ever calm in demeanour and careful and exact in his use of language; and he was eminently just and upright in all the affairs of life.

He was elected a Member of the Institution on the 1st May, 1860.

JAMES DREDGE, C.M.G.,[1] born at Bath on the 29th July, 1840, was the son of Mr. James Dredge, of that city, an engineer well known as the designer of a form of suspension bridge with inclined suspension-rods carrying the roadway; a type of which a number of examples were erected in different parts of the country. The subject of this notice commenced his professional training at an early age under his elder brother, the late Mr. William Dredge, who was established in London as a civil engineer. In 1858 he entered the office of the late Mr. D. K. Clark, remaining with him until the year 1861, and during this period he made the acquaintance of the late Mr. Zerah Colburn, at that time editor of *The Engineer*. In 1862 Mr. Dredge entered the office of Mr. (afterwards Sir John) Fowler, by whom he was employed for some years on work connected with the construction of the Metropolitan District Railway.

In 1865 Mr. Colburn, having resigned the editorship of *The Engineer*, decided to establish a journal of his own, with the result that the first number of *Engineering* was published in January, 1866. Mr. W. H. Maw became sub-editor of the new paper, while Mr. Dredge took charge of matters connected with illustrations and also occasionally contributed editorial matter. Early in 1870, upon the death of Mr. Colburn, Mr. Dredge joined Mr. Maw as co-editor, and he continued to take a very active part in the management of the affairs of the paper until he was stricken with an attack of paralysis in May, 1903.

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[1] This notice is based on the memoir which appeared in *Engineering*,

Contemporaneously with his editorial work, Mr. Dredge for more than 30 years took an exceedingly keen interest in international exhibitions. In addition to his work for *Engineering* in connection with the Vienna Exhibition of 1873, the Centennial Exhibition at Philadelphia of 1876, and the Paris Exhibitions of 1878 and of 1889, he was a member of the Royal British Commission for the Chicago Exhibition of 1893, was officially connected with the Antwerp Exhibition of 1894, served as Commissioner-General for Great Britain for the Brussels Exhibition of 1897, and was one of the Vice-Presidents of the British Commission for the Milan Exhibition of 1906. For his work in connection with the Paris Exhibition of 1889 he was appointed an Officer of the Legion of Honour, and for his services with respect to the Brussels Exhibition he was made a Companion of the Order of St. Michael and St. George.

Mr. Dredge made several visits to the United States, where he was well known and had numerous valued friends. The first of these visits took place early in 1868, when he wrote accounts of several American works for his journal. The next was in 1876, in connection with the Centennial Exhibition of that year, when he also collected materials for a series of articles on the Pennsylvania Railroad, subsequently published in book form. In 1890 he visited New York to deliver an address on the unveiling of a statue erected to the memory of his old friend Alexander Holley. At the special request of the American Society of Mechanical Engineers, he also contributed a memoir of the late Sir Henry Bessemer, which was presented at the Niagara Falls meeting of June, 1898.

Mr. Dredge was a Member of the Institution of Mechanical Engineers and for some time served on the Council of the Society of Arts. He was also, in May, 1886, elected an honorary member of the American Society of Mechanical Engineers.

Mr. Dredge never fully recovered from the paralytic attack of 3 years ago, to which reference has been already made, but he continued to devote considerable time to the editing of *Traction and Transmission*, a publication of which he was the originator and in which he took the keenest interest, until its discontinuance in 1904. During the past 3 years he spent the greater part of his time in the south of Europe or at his home at Titchfield, in Hampshire. A few weeks before his death he returned from San Remo, where he had resided during the winter, and went to Pinner, where he died on the 15th August, 1906, aged 66. His long connection with the technical press and the prominent position which he occupied enabled him to render valuable aid in the advancement of mechanical science

during the last 40 years, and his death was widely and deeply regretted in engineering circles, where he was well known and esteemed for his ability and sterling personal qualities.

Mr. Dredge was elected a Member of this Institution on the 4th February, 1896.

JAMES RICHARD FLETCHER, born at Newcastle-on-Tyne on the 3rd October, 1849, obtained his practical training under the late Mr. Robert Morrison, at the Ouseburn Engine Works, and subsequently under the late Mr. John F. Tone. During 1871 he acted as Assistant Resident Engineer on the Newcastle and Gateshead waterworks, and in the following year he obtained the appointment of Chief Assistant in the Girder Department of the Thames Ironworks. He retained this position until 1874, when he joined the staff of the North Eastern Railway as Chief Assistant to the Resident Engineer of the Northern Division, in which capacity he designed and superintended the construction of viaducts, bridges, dock-gates and jetties; extensive doubling works; the strengthening of the high-level bridge over the Tyne, of Langley Moor viaduct, and of bridges at the Central Station, Newcastle; the erection of new superstructures at Durham, Ouseburn, and Willington viaducts, and other work. In 1899 he was appointed Engineer in charge of the Newcastle district, and held this position until his death, which occurred suddenly on the 15th April, 1906, in his fifty-seventh year. In 1901 Mr. Fletcher was elected President of the Association of Students of the Institution centred at Newcastle-on-Tyne, on which occasion he delivered an address on the development of the railway system in Northumberland and Durham. He also contributed in 1899 a Paper on "Standard Load-Gauges on Railways" [1] to the Proceedings of the Institution.

Mr. Fletcher was elected an Associate of the Institution on the 2nd February, 1875, was subsequently placed in the class of Associate Members, and was transferred to the class of Members on the 17th January, 1899.

WILLIAM HENRY GREENWOOD, born at Manchester on the 25th March, 1846, received his scientific training at the Owens College, Manchester, and at the Royal School of Mines and University College,

[1] Minutes of Proceedings Inst. C.E., vol. cxliv, p. 215.

London. In addition to other scholastic successes, he gained a Rumney Scholarship at the Owens College, a Royal Exhibition and Scholarship at the Royal School of Mines, of which he was afterwards elected an Associate, and a Senior Whitworth Scholarship in 1869. He obtained his practical experience under the late Mr. Charles Sacré, on the staff of the Manchester, Sheffield and Lincolnshire (now the Great Central) Railway, and at the expiration of his pupilage in 1871, he became Assistant Manager in the famous works of Sir Joseph Whitworth and Company, Manchester. In 1875 he went to Russia as Chief Engineer to the Imperial Abouchoff Steel and Ordnance Works, St. Petersburg. Returning to England in 1880, he accepted the post of General Manager to the Phœnix Foundry and Engineering Company, Limited, of Derby, relinquishing this appointment in the following year to become Chief Engineer and Assistant Manager of the Landore Siemens Steel Company, Limited. In 1885 he accepted the Professorship of Mechanical Engineering and Metallurgy in University College, Sheffield, carrying on at the same time an extensive consulting practice. He returned to business life in 1889, when he was appointed Manager of the Birmingham Small Arms and Metal Company, Limited, and on the acquisition of part of this enterprise by the Birmingham Metal and Munitions Company, Limited, Mr. Greenwood became and remained until his death Managing Director of the latter company, which under his able management pursued a career of progressive development and commercial prosperity. He died at his residence, The Norlands, Four Oaks, Birmingham, on the 31st October, 1905, in his sixtieth year.

Mr. Greenwood was a recognized authority on metallurgy and ammunition, and was the author of a Manual of Metallurgy, a treatise on Iron and Steel, and numerous papers, among which may be mentioned his Paper on the "Treatment of Steel by Hydraulic Pressure,"[1] read before this Institution, for which he was awarded a Watt Medal and Telford Premium. He served for several years as an Examiner in Applied Mechanics and Steam to the Department of Science and Art, and as a member of the Board of Trade Committee on Steel Anchors and Chains. He was also a Member of the Institution of Mechanical Engineers and of the Iron and Steel Institute, and a Fellow of the Chemical Society.

Mr. Greenwood was elected an Associate Member of this Institution on the 31st May, 1881, and was transferred to the class of Members on the 7th December, 1886.

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[1] Minutes of Proceedings Inst. C.E., vol. xcviii, p. 83.

ARCHIBALD POTTER HEAD died on the 21st June, 1905, at Mentor on the New York Central Railroad, from injuries sustained in an accident to the "Twentieth Century" express in which he was travelling whilst on one of his frequent business visits to the United States. The son of the late Mr. Jeremiah Head,[1] the subject of this notice was born at Redcar on the 4th August, 1866, and obtained his practical training at the works of Messrs. Hawthorn, Leslie and Company, Newcastle-on-Tyne. On the completion of his pupilage, he spent 2 years at University College, London, as a student under Professor (now Sir Alexander) Kennedy, to whose influence and instruction Mr. Head always gratefully acknowledged his indebtedness. After serving 3 years as an assistant to his father, he became a partner in 1894 in the firm of Jeremiah Head and Sons, and carried on business in Westminster in conjunction with his father until the latter's death in 1899. After that date, he practised alone until 1904, when he took his brother Mr. B. W. Head into partnership.

In addition to his practice at home, Mr. Head succeeded his father as Managing Director and Engineer of the Otis Steel Company, Limited, an English company having steelworks at Cleveland, Ohio, and his firm were the European representatives of the Wellman-Seaver, Morgan Company, Limited, of Cleveland. Mr. Head also acted as Consulting Engineer to the Royal Spanish Arsenal at Trubia, for the installation of the whole of their new cartridge-making plant, plate-rolling mill and other equipment. In the same capacity he was responsible for the construction of steel-making plants for the North Eastern Company, Middlesbrough; Vickers, Sons and Maxim, Limited, Sheffield; the Earl of Dudley's Round Oak Works, Brierley Hill; Acieries de Longwy, France; and many other companies. His American interests necessitated his spending a considerable portion of his time abroad, chiefly in the United States, and a short time before his death he undertook a business tour round the world. It was while returning from the last of his visits to Cleveland, Ohio, that he met his death. Mr. Head was a Member of the Institution of Mechanical Engineers, the Institution of Electrical Engineers, and the Iron and Steel Institute. He lectured on the South Russian iron-industry before the Society of Arts, and made valuable contributions to the proceedings of other bodies, as well as to the columns of the technical press. In conjunction with his father, he contributed in 1899 to

[1] Minutes of Proceedings Inst. C.E., vol. cxxxvi, p. 347.

the Proceedings of this Institution a Paper on the "Lake Superior Iron Ore Mines,"[1] for which he was awarded a Telford premium.

Mr. Head was elected an Associate Member of this Institution on the 6th March, 1894, and was transferred to the class of Members on the 11th December, 1901.

FREDERICK BENBOW HEBBERT, born on the 10th November, 1854, was educated at Wellington College and received his scientific training at the Royal Indian Engineering College, Coopers Hill. In 1874 he joined the Public Works Department of India and was employed as an assistant engineer on the Wardha Valley Railway and Burma Railways, and on the Wien Gunga Bridge, Chhatisgarh State Railway. In 1882 he was placed in charge of a division of the Simla Imperial Circle, and having been promoted to the rank of Executive Engineer, he took part, under Mr. H. Irwin, C.I.E., in the construction of large buildings for the Government of India and also of Simla Town Hall. With the completion of the Simla buildings, Mr. Hebbert's actual constructional work came to an end. His later career was devoted to the administrative work for which his abilities best suited him, and in which he made his mark as an exceptionally able, conscientious, and energetic official. In 1887 he was appointed Deputy Consulting Engineer for Railways, at Lucknow, and thereafter he held in succession the posts of Under Secretary for Railways, Bengal; Assistant Secretary and Deputy Director-General of Railways to the Government of India; Manager of the Burma State Railway, and Agent for the Burma Railway Company. Returning to Government service in 1898, he reverted for a time to his former appointment at Lucknow, and was subsequently selected to serve on the Committee appointed to decide the question of gauge in Southern India. Early in 1904 he was posted to Calcutta as Consulting Engineer to Government for the East Indian, Eastern Bengal and Bengal-Nagpur Railways. He held this important appointment until February, 1905, when his health broke down and he was ordered home under medical advice. He died at Cannes on the 27th March, 1905, in his fifty-first year, Wielding a ready and fluent pen, he never hesitated to give clear and forcible expression to the decided views which he held on matters of railway policy and administration; he made no enemies,

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[1] Minutes of Proceedings Inst. C.E., vol. cxxxvii, p. 1.

however, his integrity of character and irresistible charm of manner invariably winning the regard of those with whom he came into contact.

Mr. Hebbert was elected a Member of the Institution on the 4th February, 1890.

JOHN STEVENSON MACINTYRE, born on the 13th April, 1839, at Shenton, Notts, was educated privately and at the Andersonian College, Glasgow, and obtained his practical experience as an assistant to Mr. H. H. McClure, of Glasgow, between 1855 and 1860. In the latter year he joined the staff of the late Mr. Robert Sinclair, Consulting Engineer to the Eastern Counties Railway, and subsequently took an active part in the extension of the lines to the metropolis when the system became the Great Eastern Railway. After the retirement of Mr. Sinclair, Mr. Macintyre continued in the service of his successor, Mr. Edward Wilson, and on the latter's death in 1877, he entered into partnership with Mr. Wilson's nephew and carried on an extensive consulting practice in Westminster until 1883, after which date he practised on his own account until his death. Between 1878 and 1883 he carried out important harbour-works at Harwich, designed to accommodate the continental traffic of the Great Eastern Railway and comprising the reclamation of a large area of foreshore and the construction of a large quay, with warehouses, sheds, hotel and office-buildings, and extensive railway-sidings. Whilst in independent practice, Mr. Macintyre was employed by various rating-authorities in connection with several large railway rating cases and assessments, work for which his expert knowledge of the cost of railway-structures and the maintenance and renewal of railway-lines specially qualified him. He died at Ealing on the 20th November, 1905, aged 66. His wide experience, allied to careful and methodical business habits, rendered him a valuable engineering witness, whilst his integrity of character and unswerving loyalty to clients and colleagues were widely recognized and appreciated in professional circles.

Mr. Macintyre was elected a Member of the Institution on the 3rd December, 1867.

JOAQUIM GALDINO PIMENTEL, born on the 22nd April, 1849, received his scientific training and graduated in the Central College of Rio de Janeiro, passing out with the diploma of Civil

Engineer in 1872. Subsequently he gained practical experience in the workshops of the St. Leonard Company, at Liége, and on the Belgian State railways. During his stay in Belgium, he studied astronomy at the Royal Observatory, Brussels, and published his first contribution to astronomical science, a study of star motions, in 1874. In 1875 he was appointed by the Brazilian Government Engineer of the Sorocabana Railway, and in the following year he accepted the post of Professor of Astronomy or Celestial Mechanics in the Polytechnic School of Rio de Janeiro, at the same time engaging in private practice as a civil engineer. In the latter capacity he designed and erected various buildings in the city, and constructed the Mogyguassu branch of the San Paulo Railway, the Copacabana street-railway and other works. He was the author of several works on scientific and technical subjects, and was a member of the principal local scientific societies. He died at Rio de Janeiro on the 26th October, 1905, aged 56.

Mr. Pimentel was elected an Associate of the Institution on the 5th May, 1874, was subsequently placed in the class of Associate Members, and was transferred to the class of Members on the 2nd December, 1884.

HENRY PRINCE received his scientific training at King's College, London, and after serving a pupilage to Mr. W. B. Adams, at the Fairfield Works, Bow, he acted as an assistant on various works for short periods and also engaged in consulting practice on his own account. In 1858 he obtained an appointment as an assistant engineer in the Public Works Department of India and was employed in the Calcutta Canal division on the construction of iron bridges and in laying out the new town of Muttra. He was next placed in charge of the Iron Bridge Yard at Calcutta, a large factory supplying the material for bridges, roofs, and other works required by the Indian Government. In 1863 it was decided to close the Bridge Yard, and after serving for a short time on special duty at the Burrakur bridge, then in course of construction, Mr. Prince was appointed Engineer in charge of the penal settlement at Port Blair in the Andaman Islands. Arriving at his post in September, 1863, he found the settlement in a very unsatisfactory state, the buildings being inadequate and unsanitary, and the convicts suffering from diseases arising from their wretched condition. Mr. Prince at once set to work to effect the needed improvements, with such success that when he left Port Blair in

1866, every man was properly housed and had been taught some trade or handicraft, and convict labour had been utilized to build jetties, roads, saw-mills, military and civil buildings, to work quarries, and to reclaim swamps and cultivate the land. In 1866 Mr. Prince was transferred to Rangoon, where he had charge of the town and district and of the military cantonment and port. In 1869, after having officiated for a short period as Chief Engineer and Secretary to the Chief Commissioner of Burma, Mr. Prince was appointed Superintendent of Works in the Eastern Circle of Burma, and subsequently, Engineer of the Rangoon and Prome railway, for which the surveys, plans, and estimates were prepared under his direction. He held temporary charge during 1872 of the Government workshops at Roorkee, and in the following year he was posted to the North-West Provinces as Superintending Engineer of the Western Circle. Whilst holding this appointment, he constructed the first length of the light-railway system of the Provinces. On his return from furlough in 1878 he was appointed Engineer-in-Chief of the Provincial State Railways, and retained this post until he retired in 1880, having risen through all grades of the service to the rank of Superintending Engineer, third class. After his retirement, Mr. Prince acted for some years as Consulting Engineer to the Bengal and North-Western and the Rohilkhand-Kumaun railways. He died in London on the 10th February, 1906.

He was elected an Associate of the Institution on the 3rd March, 1863, and was transferred to the class of Members on the 6th December, 1873.

GEORGE ERNEST BERGMAN, born on the 13th August, 1874, was educated at Merchant Taylors School and graduated at Cambridge University in 1896. He obtained his practical training under Messrs. James Simpson and Company, of Pimlico, remaining in their service as an assistant on the expiration of his pupilage. He then went out to West Africa as an assistant amalgamator to the Ashanti Goldfields Corporation, at Obuassi, where he had charge of a twenty-stamp gold mill. On his return to England, he was employed by Messrs. Middleton, Hunter and Duff as Resident Engineer in charge of a hot-water and water-softening plant at the Three Counties Asylum, near Hitchin. On the completion of this work he obtained an appointment on the staff of the Assam-Bengal Railway, and took up his duties in Assam early in 1905. He met his death on the 14th November, 1905, as the

result of the accidental overturning of an engine which he was running over a light line to a quarry.

Mr. Bergman was elected an Associate Member of the Institution on the 8th January, 1901.

THOMAS PERCY GUNYON, born on the 4th March, 1854, was educated privately for the engineering profession, and served his pupilage to the late Sir Joseph Bazalgette, C.B., Past-President. At the expiration of his pupilage in 1872, he entered the Engineer's Department of the Metropolitan Board of Works, and afterwards, under the Chief Engineer, took charge of the subways vested in the Board and its successors, and of the working of the Electric Lighting Acts and Orders. At the advent of the London County Council, Mr. Gunyon also dealt for some considerable time with engineering matters arising under the various Tramways Acts and in connection with the housing-schemes promoted by the Council. He also carried out in a highly satisfactory manner the electric lighting of Claybury Asylum. The electric lighting of the Victoria Embankment, the central and other offices, the fire-brigade stations, and many other places, was also carried out under Mr. Gunyon's direction; and he was the principal inspector of electric-lighting arrangements at all London theatres and other places of public amusement. He also rendered good service to the Council in connection with electrical subjects before Committees of Parliament and at Board of Trade inquiries. Mr. Gunyon died, after a short but painful illness, on the 13th June, 1906, at the comparatively early age of 52. His genial disposition and readiness at all times to advise and assist others earned for him the respect and esteem of his colleagues and subordinates.

He was elected an Associate Member of this Institution on the 25th May, 1880.

HENRY ALLAN MOSS, born on the 17th November, 1863, passed through the 3 years' course at the Royal Indian Engineering College, Coopers Hill, where he distinguished himself in mathematics; and after obtaining his practical training under the late Mr. J. A. B. Williams, Waterworks Engineer of Cardiff, he joined the Public Works Department of Madras in 1886. He was first posted to Bezwada, and subsequently took charge of the

Northern Sub-Division, with which the Bezwada district was incorporated. For several years he was engaged chiefly on irrigation work in the Godavari and Kistna deltas, but for nearly 8 years before he left India on furlough at the end of 1903, he was stationed at Madras, where he occupied the post of General Superintendent of the Public Works Department stores and workshops. The last important work in which Mr. Moss participated was the Cauvery Dam project, in the execution of which he expected to take part on his return to India. He, however, died in England on the 9th September, 1905, within a fortnight of the date fixed for his departure. Whilst at Madras, Mr. Moss brought out, in conjunction with Colonel A. W. Smart, R.E., their invention of lift shutters or movable weirs, which were introduced on the large anicuts and other regulators of the Cauvery Delta system and subsequently adopted in other parts of India.

Mr. Moss was elected an Associate Member of the Institution on the 4th March, 1890.

THOMAS PERHAM, born on the 19th June, 1840, was educated at the Bristol Grammar School, and, after serving a pupilage to Messrs. John Penn and Sons, of Greenwich, he left this country for New Zealand in 1864. On arrival in the colony, Mr. Perham joined the Provincial Survey Department of Canterbury, and after serving several years as draughtsman and mining surveyor, he was appointed in 1870 Assistant Marine Surveyor under the New Zealand Government, in which capacity he made a hydrographic survey through the Fijian group, and designed harbour improvements for Levuka, Fiji, and Coromandel, Auckland. In 1872 he joined the Public Works Department, and was engaged until 1885 in the design of bridges, wharves and other structures, and on surveys and improvement-works in connection with harbours and rivers in various parts of the colony. Subsequently for several years he engaged in private practice, but rejoined the department in 1893 as designing draughtsman. In 1897 he was transferred to the Mines Department as Engineer for Water Conservation, in which capacity he designed the Eweburn dam, near Naseby, Otago, the largest dam constructed in New Zealand for supplying water to the mines, its holding capacity being approximately 500 million gallons. When the goldfields are worked out in course of time, the water will be made available for irrigation in a region where the average rainfall is exceptionally low. Mr. Perham retired from

the Government service shortly before his death, which occurred at Wellington on the 16th September, 1905.

He was elected an Associate Member of the Institution on the 6th December, 1892.

LOUIS CHARLES DO ROZARIO was born on the 28th October, 1863, and after passing through the engineering course at King's College, London, and gaining the Associateship of the College, he served a pupilage to the late Sir John Hawkshaw, Past-President, from 1884 to 1887, during which period he was employed on the design and construction of the Severn Tunnel railway. After a visit to Hong-Kong, where his family resided, he proceeded in 1888 to the Philippines and served for several years as a District Engineer on the construction of the Manila-Dagupan Railway. In 1891 he returned to Hong-Kong, where he practised on his own account as a civil engineer, but on receiving an accession of fortune, he retired from the active pursuit of his profession, only advising occasionally in engineering matters in an honorary capacity. He died at Hong-Kong on the 12th December, 1905.

Mr. Rozario was elected an Associate Member of the Institution on the 2nd April, 1889.

FREDERICK SLADE, born on the 28th November, 1823, was the second son of the late Mr. Henry Slade of Aston Upthorpe, near Wallingford. Destined for agricultural pursuits, the subject of this notice was attracted to the engineering profession during the early days of railway construction. In 1846 he entered the service of Messrs. Tredwell Brothers, contractors, and continued in their employment, chiefly as Resident Engineer, until the completion of their last contract in 1872. During this period he was employed on the construction of the Berkshire and Hants, Oxford and Rugby, Bradford and Bathampton, High Wycombe and Thame, and other railways; harbour- and dock-works at Porthcawl; and improvement-works at Bristol harbour. In 1872 he was appointed by Mr. F. C. Stileman to superintend the construction of the Ramsden Dock and other works at Barrow-in-Furness, on the completion of which in 1879 he retired from professional life.

Mr. Slade devoted the remainder of his days chiefly to scientific

pursuits and to active participation in local affairs. He was keenly interested in astronomy and was also an enthusiastic and able meteorologist and a Fellow of the Royal Meteorological Society. His daily records of rainfall and other meteorological conditions at Beckford, extending over a period of 22 years, were compiled with painstaking care and accuracy; and he was well versed in many branches of natural knowledge, to the pursuit of which he brought a trained observation and a keen enjoyment of outdoor life. He died at Beckford, near Tewkesbury, on the 1st December, 1905, in his eighty-second year. In private life his wide culture and attractive personal qualities rendered their possessor a welcome acquisition in social gatherings and endeared him to a large circle of friends.

Mr. Slade was elected an Associate of the Institution on the 5th December, 1876, and was subsequently placed in the class of Associate Members.

THOMPSON WHITWORTH, born at Batley, Yorkshire, on the 19th May, 1857, served his apprenticeship to Messrs. W. and J. Cardwell, Engineers, of Dewsbury, and, after gaining experience as a draughtsman with Messrs. Greenwood and Batley, of Leeds, he obtained an appointment as Engineer and Assistant Manager to Messry. Darley and Butler, at Tuticorin, Southern India. He served three years in this capacity, from 1881 to 1884, when, as the climate did not agree with him, he returned home, and for a short period acted as Chief Assistant Engineer to Messrs. Barford and Perkins, of Peterborough. During 1887 he obtained experience of American engineering methods as Assistant Engineer on the staff of the New Jersey Steel and Iron Company, being employed on the design of bridges and other work. Returning to England in the following year, Mr. Whitworth was employed by various firms in the design, erection, and inspection of mining and other machinery, in connection with which he undertook a voyage to Western Australia, and also on two occasions served on the staff of Messrs. S. Pearson and Son, Contractors, first as Mechanical Engineer and Sub-Agent on the Thames Tunnel Works at Blackwall, and afterwards as their managing Mechanical Engineer for the reconstruction of the Wouldham Cement Works, which the firm had acquired for the purpose of manufacturing the cement required for their various contracts. For these works, Mr. Whitworth designed improved appliances for handling and storing cement, which proved

successful and economical in operation. He died on the 30th May, 1905, aged 48.

Mr. Whitworth was elected an Associate Member of the Institution on the 7th March, 1893.

REAR-ADMIRAL SIR WILLIAM JAMES LLOYD WHARTON, K.C.B., late Hydrographer to the Admiralty, died of enteric fever and pneumonia at Cape Town on the 29th September, 1905, aged 62. Born on the 2nd March, 1843, the subject of this notice was educated at Gosport and entered the Royal Navy as a cadet in August, 1857. In March, 1865, he was confirmed in the rank of lieutenant and appointed to the "Gannet," in which he acquired his first experience of the surveying service and received the commendation of the Admiralty for the zeal displayed by him in the work performed in the Bay of Fundy. He was promoted to commander in March, 1872, and placed in command of the surveying vessel "Shearwater," first on the Mediterranean station and afterwards on the east coast of Africa. In the course of his work in the Mediterranean, he made a valuable contribution to science in the form of an investigation of the surface and undercurrents in the Bosphorus. During his subsequent commission of the "Fawn," he did excellent work in training his staff for the surveying service and succeeded in winning their personal regard and esteem as well as in imbuing them with something of his own untiring energy and devotion to duty. In 1880 he was promoted to the rank of captain, and during an interval of leisure which followed he published his "Hydrographical Surveying," which soon became recognized as the standard work on the subject. He next undertook and successfully completed some very arduous and difficult surveying work in the River Plate and Straits of Magellan, returning to England in 1884, when he received the appointment, in succession to Captain Sir Frederick Evans, of Hydrographer to the Admiralty. Captain Wharton directed the work of the hydrographic department with conspicuous ability for 20 years, a period of great and continuous expansion both in the *personnel* and *matériel* of the fleet, and of corresponding development in the hydrographic service. In accordance with the regulation respecting non-service at sea he was placed on the retired list in 1891. In 1895 he was promoted to Rear-Admiral and made a C.B., and on the occasion of the Diamond Jubilee, in 1897, he was created K.C.B. He retired from the office of Hydrographer in July, 1904.

An ardent and able worker in many branches of science, Sir William Wharton was an active member of the principal scientific societies and a frequent and valued contributor to their proceedings. He was elected a Fellow of the Royal Society in 1886, and served for several years on the council of that body. He was also a Fellow of the Royal Astronomical Society, a vice-president and a member of various committees of the Royal Geographical Society, and an *ex-officio* member of the Royal Meteorological Council. He presided over Section E of the British Association at Oxford in 1894, and again in 1904 in South Africa, where on the return journey from Victoria Falls, he unfortunately contracted the illness to which he succumbed.

Sir William Wharton was elected an Associate of this Institution on the 12th April, 1904.

*** The following deaths have also been made known since the 25th August, 1906:—

Members.

Bonn, Carl Roderique Louis Menni; *died* October, 1906.
Chapman, Robert; *died* 17 October, 1906.
Hall, William Silver; *died* 26 July, 1906.
Hogg, Alexander Lauder; *died* 7 October, 1906.
Purser, Edward; *died* 26 October, 1906.

Associate Members.

Bale, George Robert; *died* 17 September, 1906.
Barker, Joseph William; *died* July, 1906.
Borrett, Charles Robert Dudley; *died* 25 September, 1906.
Brereton, Leonard; *died* 21 August, 1906.
Grant Charles Henry; *died*
Howatson, Andrew; *died*
Maclean, John; *died* 8 July, 1906.
Middleton, Richard Henry; *died* August, 1906.
Murakami, Kiyoichi; *died* 18 August, 1906.
Odling, Francis James; *died* 10 September, 1906.
Simpkins, William; *died* 30 July, 1906.
Wise, Julian Stanton, B.Sc.; *died* 17 October, 1906.

Associate.

Hedger, Philip; *died* 29 July, 1906.

Information as to the career and characteristics of the above is solicited in aid of the preparation of Obituary Notices.—Sec. Inst. C.E., 5 November, 1906.

SECT. III.

ABSTRACTS OF PAPERS IN SCIENTIFIC TRANSACTIONS AND PERIODICALS.

New Danish Ordnance Datum. A. POULSEN.

(Ingeniøren, Copenhagen, 1906, p. 160.)

The new datum, to which are now referred all levels subsequent to the year 1900, is the mean sea-level arrived at as the average of readings of self-registering tide-gauges all round the coast of Denmark up to that year. Previously the higher datum was in use of Aarhus on the east coast of Jutland; and there was yet a higher datum of Ringkøbing on the west coast, almost opposite to Aarhus. Intermediate between these comes the Swedish datum of Stockholm, while highest of all is the Prussian. They range as follows[1]:—

Prussian datum	242	millimetres =	9·53	inches.
Former west-coast datum, Ringkøbing.	163	,,	6·42	,,
Swedish datum, Stockholm	93	,,	3·66	,,
Former east-coast datum, Aarhus, 1874	44	,,	1·73	,,
New Danish ordnance datum, mean sea-level, 1900	0		0	

The outflow from the Baltic through the Sound and the Belts naturally implies a higher datum at Stockholm than at Aarhus. On the other hand, the still higher datum at Ringkøbing is due to the prevailing westerly wind, heaping up the water of the North Sea eastwards on the west coast of Jutland. The Aarhus datum was settled in 1874 for the ordnance levels in middle and north Jutland. Previously the Ringkøbing datum was used for south Jutland. A line drawn across from east to west, from Aarhus to Ringkøbing, forms roughly the boundary between the two surveys; in consulting them therefore care is necessary to make sure which datum is referred to.

A. B.

[1] A diagram of the official datum levels of different countries, compiled by Mr. James N. Shoolbred, is given in the Minutes of Proceedings Inst. C.E., 1880, vol. lxii, p. 32.—A. B.

Railways in India.[1]

(Administrative Report by the Railway Board, 1905.)

The money figures, except where stated, are in lakhs of rupees, 1 lakh = Rs. 100,000, 15 rupees = £1.

	1905 Mileage.	1904 Mileage.
5-foot 6-inch gauge, 31st December	15,028	14,723
3 „ $3\frac{3}{8}$ „ „ „ „	11,959	11,634
2 „ 6 „ „ „ „	980	861
2 „ 0 „ „ „ „	328	328
Total	28,295	27,546
Gross earnings	4168·09	3964·97
Working-expenses	1994·00	1877·50
Net earnings	2174·09	2087·47
Percentage of working-expenses to gross receipts	47·84	47·35
Train-mileage	107,045,000	102,721,000
Passenger-journeys	248,160,000	227,100,000
Do. average fare per mile	Rs. 0·0128	not given
Do. average distance travelled	39·90 miles	39·66 miles
Tonnage	54,936,000	52,051,000
Do. average rate per mile	Rs. 0·00224	Rs. 0·00234
Do. average haul	176·60 miles	172·42 miles
	Rupees.	Rupees.
Earnings per mile open	14,731	14,384
Do. per train-mile	3·89	3·86
Working-expenses per mile open	7,047	6,811
Do. per train-mile	1·86	1·83

Total expenditure divided departmentally:—

	1905	1904
Engineering	481·59	437·28
Locomotive	702·38	672·07
Carriages and wagons	184·05	176·74
Traffic	331·02	310·25
General	294·96	281·16
Total	1,994·00	1,877·50

The employees consisted of 6,535 Europeans, 9,175 Eurasians and 436,348 natives. Total capital expenditure, Rs. 37,056·33.

ROLLING STOCK.

	Gauge.			
	5-Foot 6-Inch.	3-Foot $3\frac{3}{8}$-Inch.	2-Foot 6-Inch.	2-Foot.
Locomotives	3,759	1,827	131	58
Coaching-stock	11,575	7,896	519	277
Goods-stock	69,163	39,508	1,774	926

[1] All lines are included.

The report refers to the improved accommodation for the comfort and convenience of third-class passengers, the receipts from whom form 84 per cent. of the passenger-revenue; to the adoption of standard time, 5½ hours in advance of Greenwich; and to a preliminary report on the advisability of importing sleepers from Australia.

C. O. B.

Cape of Good Hope Government Railways.

(Report of General Manager, 1905.)

Earnings—	£	£
Passengers	1,210,041	1,251,887
Parcels	113,309	116,568
Vehicles, horses, etc.	60,183	42,548
Goods and minerals	2,334,667	2,443,173
Cartage	86,724	92,381
Live stock	89,180	73,555
Hire of rolling stock to and from foreign administrations	Dr. 5,443	26,643
Mails	37,774	36,316
Telegraphs, rents, etc.	62,406	61,248
Repayment of cost of damage by war	58,224	..
	4,057,951	4,144,319
Expenditure	3,076,920	3,719,822
Balance	£981,031	£424,497
Passenger-journeys	20,611,384	21,778,516
Goods-tonnage	1,836,946	1,930,283
Vehicles and live stock	1,051,817	1,043,698
Train-mileage	9,323,039	10,129,224
Earnings per train-mile	104·2*d.*	98·2*d.*

Detail of working expenses per train-mile and per average open mile in pence and pounds.

Maintenance	per train-mile	11·2*d.*	13·2*d.*
	per open mile	£155	£216
New works	per train-mile	0·5*d.*	1·1*d.*
	per open mile	£6	£19
Relaying and regrading	per train-mile	2·5*d.*	4·4*d.*
	per open mile	£34	£73
Locomotive charges	per train-mile	25·9*d.*	28·3*d.*
	per open mile	£358	£463
Carriages and wagons, repairs and renewals	per train-mile	7·1*d.*	8·1*d.*
	per open mile	£93	£133
Additional rolling stock, sheds, etc.	per train-mile	6·5*d.*	6·0*d.*
	per open mile	£90	£98
Traffic expenses	per train-mile	17·9*d.*	19·1*d.*
	per open mile	£248	£312
Sundries and general	per train-mile	7·6*d.*	7·9*d.*
	per open mile	£105	£129
Total	per train-mile	79·2*d.*	88·1*d.*
	per open mile	£1,096	£1,443

Average passenger haul	16 miles	15 miles
„ goods haul	186 miles	183 miles
„ load, passengers	84	85
„ goods	79 tons	75 tons

	1905	1904
Mileage open on December 31st	2,986	2,664
Do. counted as single road, of which 2,971 miles are on 3-foot 6-inch gauge, and 47 miles on 2-foot gauge	3,018	2,750

Nine lines, of an aggregate length of 801 miles, were under construction, of which four, amounting to 322 miles, were completed.

CAPITAL EXPENDITURE.

	£	s.	d.
Lines open for traffic, including rolling stock	29,973,023	10	10
Per mile	10,037	17	0
Expended on lines still under construction	957,265	18	6
Capital entitled to a full year's interest	29,047,230	0	0
Ditto for 1904	26,799,366	0	0

ROLLING STOCK.

(3-foot 6-inch lines.)	1905	1904
Locomotives	667	674
Coaching vehicles	781	782
Goods and live-stock wagons equivalent to short trucks	12,237	12,182
Other vehicles	528	544
(2-foot lines.)		
Locomotives	14	10
Coaching vehicles	31	26
Goods and live-stock wagons equivalent to short trucks	312	228
Other vehicles	3	3

The manager alludes to the great reduction in expenditure (17·28 per cent.) as largely due to retrenchment, and he refers also to the fact that the reduced tonnage at high rates is in imported traffic, the increase at low rates being mostly of native products (13·2 per cent.), presaging therefrom better results, on the whole working, in the future. To heavier engines and improved gradients are due the decreased expenses per train-mile. The local building of rolling stock is noted.

There is an informing paragraph applicable to many other colonial railways, explaining reasons for the apparent smallness of the average net load, viz., 79 tons, these being gradients, bulk of traffic in one direction, and low percentage of carrying-capacity, especially in connexion with agricultural produce, this only giving a load of from ¼ to ¾ of truck-carrying capacity. The result is that, in 1905, the average load of 79 tons yielded only 1·565*d.* per ton-mile, and the cost to haul and handle was 0·927*d.* per ton-mile.

C. O. B.

Natal Government Railways.

(Report by the General Manager, 1905.)

	1905	1904
Mileage, 31st December	906½	775¾
Average mileage worked	782¾	744½
Under construction	152	
	£	£
Revenue	2,052,448	1,933,934
Working-expenses	1,307,010	1,531,210
Net Revenue	745,438	402,724
Percentage of working-expenses to receipts	63·68	79·18
Passenger-journeys, exclusive of season tickets	2,668,028	2,710,971
Goods-tonnage	2,165,591	1,919,959
Live stock, number	118,369	110,744
Train-mileage	4,483,158	4,292,028
Engine- „	5,574,905	5,246,659
Earnings per train-mile	109·88*d.*	108·14*d.*
Expenditure do.	69·97*d.*	85·62*d.*

DETAILS OF EXPENDITURE.

	1905	1904
Maintenance, per open mile	£207	£239
„ „ train-mile	8·68*d.*	9·93*d.*
Locomotive-expenditure, per open mile	£815	£1,036
„ „ „ train-mile	34·14*d.*	43·12*d.*
Traffic-expenditure, per open mile	£509	£517
„ „ „ train-mile	21·33*d.*	21·51*d.*
General, per open mile	£139	£266
„ „ train-mile	5·82*d.*	11·06*d.*
Totals per open mile	£1,670	£2,058
„ „ train-mile	69·97*d.*	85·62*d.*

The coal-consumption per train-mile for 1905 was 88·80 lbs. at a cost of 6·04*d.*

The number of employees was as under:—

	1905	1904
White	4,789	4,848
Indian	3,176	3,027
Native	3,481	3,584
Total	11,446	11,459
	£	£
Capital expenditure on open lines	12,957,545	11,866,946
Do. under construction	108,120	4,049
Total	13,065,665	11,870,995

ROLLING STOCK.

	1905	1904
Locomotives	326	309
Tenders	57	21
Coaches	487	491
Wagons	3,377	3,448

The notable decrease in expenditure is commented on but not explained in detail. A remarkable rain and snow storm on the

31st May, causing damage to the amount of £7,540, is referred to, and also the fact that this, the Twenty-Seventh Annual Report of Sir David Hunter, is his last, previous to retirement.

In addition to the usual diagrams, map and photographs, there is appended a set of diagram sections of all the lines, giving positions of stations, tanks, passing places, turntables, ruling gradients of sections, elevation above sea, and other useful particulars. C. O. B.

NOTE.—The general gauge of the Natal Government railways is 3 feet 6 inches, called the standard gauge, and there is nothing in the report to show that there are any exceptions to this in the lines open for traffic. There is a line 30 miles long, however, under construction from Estcourt to Weenen, and another proposed, called the Stuartstown railway, which the report states are to be on the 2-foot gauge.—C. O. B.

Central South African Railways.

(Report of the General Manager, 31 December, 1905.)

		1904	1905
Mileage at end of year :—			
Single track		1,736½	
Double ,,		45	
Treble ,,		7¼	
Total		1,788¾	1,784¾
Average mileage worked		1,542	1,432
Lines under construction (miles)		643½	
,, projected (miles)		258½	
		£	£
Earnings :—Passengers		1,348,827	730,912
Goods, etc.		4,015,792	3,856,867
Total		5,364,619	4,587,779
Working-expenses		2,817,928	2,885,149
Net receipts		2,546,691	1,702,630
Percentage working-expenses to gross receipts		52·5	62·9
Train-mileage		7,321,618	7,418,243
Engine-mileage		8,840,552	9,449,558
Number of passengers		6,871,547	5,468,366
Live stock, head		679,662	593,476
Goods, general (tons)		3,904,717	3,457,158
,, departmental, &c. (tons)		648,671	781,657
Receipts per train-mile		175·9*d.*	148·4*d.*
,, per open mile		£3,479	£3,204
Working-expenses per train-mile :—	*d.*		
Locomotive department	41·8		
Maintenance	18·0		
Telegraphs	0·6	92·4*d.*	93·3*d.*
Traffic	22·2		
General	9·8		
Working-expenses per average open mile		£1,827	£2,015
Capital		£23,424,309	£21,329,983
Number of locomotives		481	480
,, carriage-stock		463	473
,, goods, &c.		7,615	7,641

The tractive power of the locomotives varies from 16,020 lbs. to 36,864 lbs.

The percentage of paying to gross load in wagons varies, according to type, from 58·82 to 69·78, more than half being 63·95.

The number of employees was—

White	6,476
Native	7,147

The report contains a reference to the General Manager's visit, in connection with light railways, to Natal, Cape Colony, and also to Egypt, a map of the railways of which is appended. The railway conference of February, 1905, of the various South African systems and of Mozambique, is mentioned, and there is also a valuable section devoted to the question of malarial fever in the low country, and the means taken against it.

The report has some especially good diagrams, maps, and photographs, and a feature of it, which is more valuable than it is usual, is a copious cross-reference index. C. O. B.

NOTE.—The gauge of these railways is generally that of the standard of South Africa, 3 feet 6 inches, but one line under construction, 27 miles long, is to be of 2-foot gauge.—C. O. B.

Railway from Morez to Saint Claude. L. REVERCHON.

(La Nature, Paris, 3 March, 1906, pp. 215–8.)

The picturesque mountain line from Morbier to Morez will shortly be completed to Saint Claude, which last-named town is already the terminus of a branch railway from La Chise. The new line will have a total length of 14·59 miles and an average gradient throughout of 1 in 80, the altitude at Morez being 2,408 feet and at Saint Claude 1,440 feet. The construction of this railway has entailed many difficulties, and there are in all twenty tunnels and twelve viaducts or bridges. The tunnels attain a total length of 5,257 yards, the principal one, between Tancua and Lézat, being 1,892 yards long. Several of the viaducts spanning torrential rivers are at very great altitudes. This railway traverses the country through which the new international line from France to Italy is projected to pass, and at Valfin, a few miles north of Saint Claude, would be situated one end of the second of the great tunnels piercing the Faucille. This tunnel would emerge on the banks of the River Bienne, about 65 feet below the Valfin Station on the new line. Saint Claude, if the Faucille tunnels are made, would thus be situated between the two longest tunnels, the one 7·45 miles and the other 8·69 miles long. By the aid of photographs of certain points on the line, a map of the country and a section of the projected railway, some of the chief features of the romantic country opened up by this railway are described. Saint Claude is already well known for

its manufactures and as a centre of numerous excursions, and is renowned for its waterfalls, grottos and fine mountain panorama.

It is stated that the engineering work of the new railway is bolder than that of any similar undertaking in Dauphiny or in the Auvergne.

G. R. R.

High-Tension Continuous-Current Railway between Cologne and Bonn.

(**Elektrotechnische Zeitschrift, Berlin, March, 1906, pp. 316-9.**)

This line was open for traffic early in the present year, and presents several points of interest in view of the special considerations underlying its design. Starting from Cologne the trains run on the municipal tramway lines as far as Rodenkirchen under a pressure of 550 volts direct current. At Wesseling, the centre of the line, which is 28·5 kilometres (17·7 miles) long, a power-station is provided, supplying direct current at 990 volts as far as the outskirts of Bonn, where recourse is again had to the municipal tram-lines.

That portion of the railway controlled from the generating-station is divided into three sections, in the first and last of which 300 ampere-hour accumulator-substations are provided, while the centre portion is fed direct. Current is taken through two trolleys from two overhead conductors of 80 square millimetre (0·123 square inch) section, suspended pendulum fashion from a single continuous steel wire supported on insulators. The return is through the rails, which are well and substantially bedded and bonded. The use of 6,000-volt single-phase current on the main line with subsequent stepping down to 200 volts on board the cars was also advocated, but rejected on account of the increase in weight caused by auxiliary switch-gear and apparatus. Two motors, each giving 130 HP. at 900 volts, are fitted to each car and suffice to propel them and a trailer car (weighing together about 54 tons) at a speed of 70 kilometres (43·5 miles) per hour.

C. J. G.

Electric Equipment of the New York, New Haven and Hartford Railroad.

(**Engineering Record, New York, 24 March, 1906, pp. 402-4.**)

The locomotives, which contain many novel and interesting features, must operate on direct current over the New York Central part of the New Haven system, and on alternating current over the remainder. Hence some duplication of parts, such as collecting devices for third rail and overhead conductors, wiring, etc., are necessary.

The main power-house is so placed that the high-voltage system of 11,000 volts will extend about 19 miles in one direction and 3 in the other, and be capable of extension approximately to 20 miles further in the latter direction; therefore about 40 miles of the trolley system can be supplied without transforming sub-stations.

The steam turbine-driven generators have single-phase ratings of 3,750 kilowatts, or about 5,500 kilowatts on three-phase, the armature winding being such that three-phase current can be obtained from the same machine. The generators have two poles, and at 1,500 revolutions per minute give 3,000 alternations per minute, or 25 cycles per second.

In view of the direct-current work, it was decided to add an additional leg to the armature-winding, so that three-phase currents could be obtained for feeding into rotary-converter stations. Other fields for three-phase power are also in contemplation.

The description of the locomotives, which is in great detail, is the main subject of the article. The running gear consists of two trucks 14-foot 6-inch centres, each on four 62-inch driving-wheels, the wheel-base being 8 feet. There are four motors, each of 250 HP. nominal capacity, but with a continuous capacity of over 200 HP. They are gearless and wound for a normal full-load speed of 225 revolutions per minute, being connected permanently in pairs and requiring about 450 volts at the terminals on alternating current, and 550 to 600 volts on direct current. The armature is not placed directly on a shaft, but is built up on a quill, through which the car-axle passes with about $\frac{5}{8}$-inch clearance all round. On this quill at each end are placed bearings which carry the field frame and a flange from which project pins parallel to the shaft into pockets in the hub of the wheel. The coiled springs aiding in this connection are fully described. Owing to the relatively low speed of the motors, which are internally of the Westinghouse type, the maximum commutator speed is very low, being less than 3,000 feet per minute when the locomotive is making 60 miles per hour. The method of cooling is fully detailed, and includes a description of the forced ventilation of the motors and rheostats.

Other points refer to the economical control of the motors when working on the direct current, as the type of motors used permits of an almost indefinite shunting of the field without affecting the commutation, whereby the use of resistances is to a great extent avoided.

An article giving outlines of this scheme appeared in the *Engineering Record* of the 17th February, 1906, and is referred to in a previous abstract,[1] but the article of which this is a summary is much fuller in detail, and specially so as regards the single-phase locomotives.

C. O. B.

[1] Minutes of Proceedings Inst. C.E., vol. clxv, p. 374.

Ferro-Concrete for Tram-Rail Bedding. E. REINHARDT.

(Deutsche Bauzeitung, Berlin, April, 1906, pp. 187–96.)

The Author describes a system of bedding tram-rails on ferro-concrete slabs in streets paved with wood blocks and asphalt, and gives the results of trials extending over 3¾ years at Schöneberg near Berlin. Instead of bedding the tram-rails on a concrete foundation they have been laid on ferro-concrete slabs consisting of concrete blocks 4 inches thick, 16 inches long and 20 inches broad, made in the proportion of one part cement to three parts gravel, and reinforced with a double network of interwoven ¼-inch round bars. The lower reinforcement is to take up the tension, and the upper bars are extended all round the blocks about 4 inches for the purpose of interlocking with concrete to be used in making up the roadway. These slabs were laid on a 1-inch top cement-mortar dressing applied to the prepared surface and so spaced that a slab lay either side of the rail-joint. These joint slabs were immediately grouted together to form a continuous slab. The slabs were therefore spaced about 7 feet apart centre to centre. The rails were then laid on the slabs with a ¾-inch clearance, which was finally closed with asphalt or cement grouting, and were embanked at the sides with concrete up to the rail-head; the spaces between the slabs were filled out with concrete, the projecting bars forming the bond. The whole roadway was then made up in the usual method with concrete. This method proved quicker in construction and permitted the tram traffic to run immediately after the rails had been laid, thus reducing the cost of construction and lessening the interference with the traffic. The Author describes the laying of a double track which was carried out at the rate of 100 yards a day against 40 yards with the older method, and at a cost of 34*s.* per yard instead of 40*s.* The article is accompanied by photographic reproductions and by a table of figures.

F. R. D.

Deformation of Railway-Tracks. G. CUÉNOT.

(Comptes Rendus de l'Académie des Sciences, Paris, 1906, vol. cxlii, pp. 770–2.)

The Author has investigated the influence of the railway-sleeper on the deformations of the rails, using for his experiments wooden sleepers of different lengths, a steel sleeper in use on the French State railways, and a new type of sleeper containing both wood and steel. This sleeper is made of two U-shaped bars of metal, turned back to back, and having between them two rectangular blocks of wood separated by an air-space. It has been thought that the load on a sleeper is distributed over all its length, and that therefore its depression may be decreased by increasing its length, but the Author's experiments show that this is not the case. Long sleepers

(more than $2\frac{1}{2}$ yards) take, when loaded, the shape of a curve concave upwards, and the rails are bent inwards. Short sleepers of less than 2·3 yards bend into a curve convex upwards, and the rails are turned outwards. Wooden sleepers, of which the length is between 2·3 and 2·4 yards, keep nearly straight when loaded, without any turning over of the rails. The compound sleeper of similar length has also given good results.

W. C. H.

New Sleeper- and Timber-Preserving Plant.

(Engineering News, New York, 3 May, 1906, pp. 490–3.)

The Atchison, Topeka and Santa Fé Railway has recently completed a large new plant at Somerville, Texas, on the main line. The plant has five treating-cylinders or retorts. Each cylinder will take a charge of about 600 hewn sleepers of 3·4 cubic feet each. It is expected that two of the cylinders will be used principally for bridge-material. Only creosoting will be effected at this works, as it is considered that pure dead-oil of coal-tar, commonly called creosote, is the best preservative in commercial use for all kinds of timber. The creosoting will be done under the Rueping process, by which complete penetration of the soft wood is claimed to be obtained with 4 to 5 lbs. of oil per cubic foot as against 10 to 15 lbs. under the old process; but any piles to be used in bridges or slips along the coast, where the *teredo* or *limnoria* are found, will be treated by the old process, using not less than 20 lbs. per cubic foot. The creosote used has a specific gravity of 1·03 at 100° F., and remains liquid down to 90° F. The treatment under the Rueping process is to some extent a reversal of the old system, as creosote is forced into the sleepers under air-pressure instead of being put in under a vacuum. There is a pressure cylinder to each pair of impregnating cylinders. The latter are 6 feet 2 inches in diameter and 132 feet long, and are designed for a working-pressure of 250 lbs. per square inch with creosote oil at a temperature of 225° F.; they are built of alternate inner and outer rings, connected together with double riveted lap joints, while the longitudinal joints have double butt strips. At each end is a cast-steel flange trebly riveted to the shell, and to these the steel doors are hinged. On the top of the cylinder is a dome fitted with two safety-valves and an 8-inch air-pipe connection. The pressure-cylinders are 6 feet in diameter and 106 feet-long. The trains of sleeper-cars are put in and taken out at the same end of the cylinder; the cars run on tracks of angle-bars riveted to supports on the shell of the cylinders. After filling an impregnating-cylinder with sleepers, and a pressure-cylinder nearly full of creosote, both cylinders are first subjected to air-pressure of 75 lbs. per square inch; the creosote in the pressure-cylinder is then allowed to flow into the impregnating-cylinder by gravity until the latter is full. The pressure-pump is then restarted,

forcing additional creosote into the wood at gradually increasing pressures up to 150 lbs. per square inch, which pressure is maintained for 15 minutes. The pressure is then released and the oil in the impregnating-cylinder allowed to flow by gravity into underground tanks. To remove any surplus oil a vacuum of 22 inches is gradually created in the cylinder and maintained for a few minutes; the oil being allowed to drain off. The series of operations occupies 4 hours and 20 minutes.

A. W. B.

Artificial Preservation of Railway-Sleepers and Wood Planks. N.

(L'Électricien, Paris, 1906, vol. xxxi, pp. 209–11.)

This Paper contains a description of a process for treating timber, such as railway-sleepers, telegraph-poles, and wood-paving blocks, to prevent its decay when in use and exposed to all kinds of weather. The timber is first placed in closed vessels and injected under pressure with a dilute solution of an appropriate salt for the end in view, such as copper or zinc sulphate or sodium silicate. The wood is then subjected to the action of an alternating current, which alters the state of the fibres and sap and of the salts previously injected. These soluble salts combine with the organic elements of the sap and incrusting matter to form insoluble salts, which remain fixed on the fibres and prevent their putrefaction. The alternating current also destroys all the vegetable or animal germs contained in the wood. The fibres themselves undergo a transformation which increases their tenacity and mechanical resistance. Direct currents have been found to produce injurious effects on the wood by their electrolytic action, and therefore alternating currents are alone used. For this electric treatment the arrangement is as follows. Over a trough in the ground, containing a solution of the salt with which the timber has previously been injected, there is placed a cover consisting of wooden spars with spaces between them. This is in turn covered with a "carpet-electrode," described below; a row of sleepers or blocks packed closely together is placed on top; then another electrode is placed over this row and another row of sleepers above, and so on till a pile some 5 feet high is erected. The alternate electrodes are connected to opposite poles of a source of electricity, giving a mean pressure of 110 volts. The electrodes are composed of two thick layers of jute, between which are placed a thin layer of spongy cotton and a very pliable layer of brass gauze. By means of an electric pump, salt-solution is raised from the trough and led into the mass of wood above at different points, so that electrodes and wood are kept saturated throughout the process. The Paper states that wood submitted to this treatment completely resists putrefaction and shows a remarkable hardness.

W. C. H.

Grid-Fencing for Railway-Crossings. S. Winkel.

(Ingeniøren, Copenhagen, 1906, pp. 84–5.)

To obviate the expense of gates, gate-house and gate-keeper, at level crossings on his own property, the Author has adopted the so-called American grid, of which a drawing is given. It may be described as a louvre or Venetian blind, 5 feet high, with vanes or laths inclined at 45 degrees; but instead of standing upright, the whole is laid flat on the ground, extending transversely between the rails, and beyond them on each side of the track. The vanes are 2-inch planks, $4\frac{1}{2}$ inches wide, and spaced about $3\frac{1}{4}$ inches apart. These grids are laid along each side of the level cross-road, and thus extend 5 feet along the railway in each direction. Their sloping vanes and spaces prevent horses and cattle from getting their feet between and down on the ground beneath; and thus effectually prevent their straying from the cross-road on to the line, or from the line into the cross-road. Sheep are not always deterred by this means from straying, any more than they are even by barbed-wire fencing. When fields are not being used for grazing, the grids can be taken up and preserved indoors. They cost only one-third of gates, and require no attendance.

A. B.

Vitrified-Shale Fence-Posts.

(Railway and Engineering Review, Chicago, 17 February, 1906, p. 111.)

With the growing scarcity of timber and the advance in the price of fence-posts there has come a demand for post-material which is indestructible by fire and will not decay. The lasting qualities of vitrified clay or shale are known, and if it could be made in form to possess requisite strength against breakage by accidental side blows or by wire-tension it would be an ideal material for the purpose. The National Vitrified Post Company of Kansas City, Mo., is now manufacturing such a post. The post is of circular section and hollow, being $6\frac{1}{2}$ inches in diameter at the base, 3 inches in diameter at the top, and $6\frac{1}{2}$ feet long. The shell is $1\frac{1}{4}$ inch thick at the bottom, and $\frac{5}{8}$-inch thick at the top. The post weighs 50 lbs. It is moulded by machinery and is pierced at intervals for attaching fence-wires. It is then branded with the name of the railway-company and in the various processes of manufacture is burnt to vitrification. Corner posts are made heavier than the line posts, being 6 inches square.

Posts of this kind have been in use on the Missouri Pacific Railway at Sedalia, Mo., for 10 years without breakage or deterioration in any respect. It is also claimed that these posts are cheaper than wooden, steel or reinforced-concrete posts.

J. M. M.

Snow-Plough for Dunderland Railway, Norway. HBG.

(Teknisk Ugeblad, Christiania, 1906, pp. 57–8.)

The Dunderland Iron-Ore[1] Railway from Storforshei to Guldsmedvik, near Mo in Ranen, runs mainly through cuttings in sidelong ground. Following the pattern most generally employed in America, a snow-plough built at the Skabo Railway Wagon Works throws the snow to one side only, and is thus adapted for clearing a double-track line. Its length over all is 10·8 metres (35½ feet); breadth 3·2 metres (10½ feet); length of wings 2·8 metres (9¼ feet); breadth over spread wings 4·6 metres (15 feet); height, exclusive of look-out box in roof, 3·8 metres (12½ feet); weight 16 to 17 tons. A photograph shows its general appearance. It is carried on a couple of four-wheel bogies; owing to the heavier and greatly varying load on the leading bogie, this has four bearings on each axle, and no springs. The share or lifting blade in front has an upward slope of 22 degrees. The snow is thrown off by a conical breast, moulded of oak boards. Most of the snow is thus delivered from the plough at about 3·5 metres (11½ feet) above rail-level, and forms a sloping bank alongside the line. The plough is made strong enough to bear being pushed by two or three powerful locomotives. For spreading the bank wide enough to leave room for subsequent deliveries, wings are pivoted on each side of the plough; they are iron frames filled in with oak boards, and are spread by a screw, and held in position by a brake so as to yield to any excessive strain. The trailing bogie carries knives in front, adjustable in height for clearing the snow from between the rails to a depth of 4 centimetres (1½ inch). The leading bogie carries the usual brooms for sweeping the rails. The guard looks out from the roof-box, while another man in the cab minds the wings and knives.

A. B.

Explosion of a Locomotive at St. Lazare Station, Paris.

S. PERISSÉ.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, 31 January, 1906, pp. 36–70.)

It is pointed out that three inquiries have taken place into the causes for this accident, an administrative inquiry for which Mr. Frémont acted as a secretary, a judicial inquiry conducted by the Author, and a third carried out by the Engineers of the Western of France Railway Company. The results of two of these investigations have been already published, and the verdict of the judicial inquiry with the wide powers granted to the Author is now made known. The experts constituting the committee for the

[1] See Minutes of Proceedings Inst. C.E., 1900, vol. cxliii, p. 369.

administrative inquiry have disavowed the conclusions of Mr. Frémont, and they assert that his report, as published, by no means represents their opinions, but it would appear that they agree with him that the accident was due to the brittleness of the plates with which the fire-box was constructed, and that the railway company is free from blame in the matter, since the plates when tested on delivery gave satisfactory results, and there was nothing in the regulations at that time which involved the employment of impact-tests for such plates for boiler-making purposes. The engineers of the railway company have not pronounced an opinion as to the cause of the explosion, but there are good grounds for concluding that they considered that the accident was probably due to excess of pressure. The same view has been advanced by many very competent authorities, and the Author, during the first 6 days of his inquiry, carried out a very exhaustive set of researches to elicit the facts as to excessive pressure, which appeared to be the most probable cause of the accident, in consequence of the division into so many fragments of the plates of the cylindrical body. He was compelled, however, to abandon this hypothesis, and to surmise that the explosion was due to deformations caused by dilation and contraction set up in consequence of the use of flanged steel tubes and fire-box stays which were too thick for their relatively short lengths. The grounds for these views are given at considerable length and with numerous diagrams and photographs of the fragments of the fire-box and boiler. On behalf of the engineers of the railway company these conclusions are combated by Mr. R. Dubois and certain observations by Mr. H. Le Chatelier are appended.

G. R. R.

Common Standard Locomotives in America (Harriman Lines).

(American Engineer and Railroad Journal, New York, 1905, October, pp. 353–6, November, pp. 400–2, December, pp. 442–3.)

These articles are a further continuation of previous articles on the same subject.[1] There are but two sizes of boiler-barrels, all being 70 inches in diameter, except the boilers of the consolidation locomotives which are 80 inches in diameter. The three sizes of road-engines have the same size fire-box, 108 inches long by 66 inches wide. All have the same grates.

In all of the boilers the fire-box crown sheets are supported by slings to T-iron roof-bars which are continuous through the crown. All the crown-sheets are flat and all the boilers are straight top except as the fire-boxes slope to the rear. The boiler-sheets are telescopic in all the designs. The circumferential seams are double riveted. The horizontal seams are known as the Vauclain diamond

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[1] See Minutes of Proceedings Inst. C.E., vol. clxii, p. 434, and vol. clxiv, p. 441.

boiler-seam, which has an efficiency of 96 per cent. The very long seams are welded over a length of 11 inches at each end. Except the switch-engines, which carry 180 lbs. per square inch steam-pressure, all the boilers are built for 200 lbs. with a seam-factor of five.

These standard boilers have been designed with unusual care in order to reduce to a minimum the amount of work in the boiler-shop. Dimensioned drawings of the boilers are given in the text, and the construction of the leading and trailing trucks of the engines are fully illustrated.

The goods-locomotives have Vanderbilt tenders with a capacity of 7,000 gallons of water and 14 tons of coal. For passenger-locomotives very large tenders with a capacity of 9,000 gallons of water and 10 tons of coal were adopted. They are believed to be the largest tenders used in regular passenger equipment. The tenders of switching-engines have a capacity of 4,000 gallons of water and 5 tons of coal. Drawings of the tenders for goods-engines are given in the text, and details of the truck for goods-engine tenders are also shown.

J. M. M.

Concrete Pavements in Denver.

(Engineering Record, New York, 31 March, 1906, pp. 416–7.)

A new departure, successful in its results, has been made in laying concrete pavements, first between the rails of tracks in Denver City, and subsequently, owing to its success, elsewhere, by the Board of Public Works. The road-bed being graded 9 inches below the finished surface, small dams at intervals were then built across the roadway high enough to ensure at least 6 inches of water over centre and 2 inches at the highest point of the subgrade; water was then admitted and allowed to sink, when the surface was rolled and covered by a bed of cinders or sand mixed with gravel compacted by wetting and rolling. On this was laid successively beds of 4 inches of 1 : 3 : 7, and 2 inches of 1 : 2 : 4 concrete, the materials for the top course being mixed while the bottom was in hand, so as to obtain a perfect bond.

The contract price in the instance given, a 16-foot alley, was 55 cents (2*s.* 3½*d.*) per cubic yard for grading, and $1·08 (4*s.* 6*d.*) per square yard for the pavement. This includes a 5-years' guarantee. The article states that experience shows that it may be desirable to lay the concrete in a single course, using probably the richer mixture.

C. O. B.

Investigation of Overloaded Bridges.

W. J. WATSON, M. Am. Soc. C.E.

(Proceedings American Society of Civil Engineers, New York, April, pp. 326–35.)

In computing the stresses in the members of old bridges, the writer makes use of the following expression for the allowance (I) to cover the stresses due to impact, vibration, etc., viz.:—$I = L \frac{L}{L + D}$, where L is the stress due to live load considered as a static load and D is the stress due to dead load. Any secondary stresses due to eccentric connections or other defects in design or execution should be added to obtain the maximum stress. The maximum intensity of stress in any member in tension, taking all secondary stresses into account, should never exceed 75 per cent. of the elastic limit of the material for members symmetrically connected, or 60 per cent. of the elastic limit for such members as angles connected by one leg only. This would give for symmetrically connected members in tension a maximum working intensity of stress of 20,000 lbs. per square inch for wrought iron, 24,000 lbs. per square inch for soft steel, and 26,000 lbs. per square inch for medium steel. The chief point to be noted in examining the compression-members of old bridges is whether or not there is sufficient stiffening. With respect to riveted joints, the writer's experience has convinced him that in general rivets will not begin to work loose until the intensity of stress in shear and bearing amount to about 22,500 lbs. per square inch, and 45,000 lbs. per square inch respectively, owing to the fact of the working-stresses being almost entirely transmitted by the friction between the contact surfaces at the joint. In the case of plate girders, the writer suggests that, instead of taking the effective depth of the girder as the distance between the centres of gravity of the two flanges when calculating the flange-stresses, and as the distance between the lines of rivets when calculating the number of rivets, a depth intermediate between these two should be taken as the effective depth for all purposes.

A. W. B.

Concrete Bridges over the River Iller, near Kempten.

COLBERG.

(Deutsche Bauzeitung, Berlin, April, 1906, pp. 219–21 and 232–6; May, 1906, pp. 261–3.)

The Author describes the construction and erection of three large concrete railway-bridges over the River Iller, near Kempten, to replace the old iron bridge. Concrete was chosen in order to reduce the cost of maintenance. All three bridges are exactly alike and are of the three-pin joint type. Each carries a double track of rails and consists of three viaduct arches of 71 feet span, and a main arch over

the river of 211·5 feet span with 100·5 feet headway above the mean water-level. Two of the three bridges are erected on one and the same foundation with a clearance of only 4 inches. This system of a double bridge was adopted in order to reduce the lateral stresses when unsymmetrical loading occurs. The grade of the tracks over the bridge is 1 : 100. The pin-joints of the main arch are made of large cast-steel blocks, whereas the joints for the secondary arches are simply formed of $\frac{5}{16}$-inch rolled sheet-lead placed between the joint bed-stones. The main pin-joints were placed in position, bolted together in order to avoid lateral displacement, and the joint splay is taken up by cork plates encased in thin zinc sheeting. Great care was taken in the choice of materials to be used for the concrete, as severe stresses had to be taken into account. The concrete for the main arch to withstand maximum stresses of 500 lbs. per square inch, was made in the proportion of 1 part cement, 2½ parts sand, and 5 parts crushed dolomite rock; for the abutment piers, with a maximum stress of 370 lbs. per square inch, 1 : 3 : 6 and the foundations 1 : 5 : 9. The 28-day tests of the concrete for the main arches show a crushing value of 1·85 tons per square inch. The bedding stones for the pin-joints were specified to withstand a crushing load of 2½ tons per square inch, and were made of cement, sand and crushed basalt in the proportion of 1 : 2 : 2. The 90-day tests of this concrete show an ultimate strength of 3·05 tons per square inch. Breeze concrete in the proportion of 1 : 12 was used to fill out the arches. Special inspection chambers were constructed in order that the pin-joints of the main arches can be from time to time controlled. The results of the concrete tests showed that the unwashed sand, as a rule, gave better results than the washed materials. The paper is accompanied with numerous illustrations showing the method of erection and the false staging, as well as diagrams and tables of the concrete tests.

F. R. D.

Flat-Span Reinforced-Concrete Bridge at Memphis.

(Engineering Record, New York, 7 April, 1906, pp. 446–7.)

This very unusual structure is a reinforced-concrete cantilever single span of 100 feet with only 4 feet rise. Omitting the reasons for the necessity of the cramped headway leading to this design, the bridge may be shortly described as having a total width of 31 feet, made up of a 16-foot roadway with a 4-foot walk on each side protected by an iron railing, the two concrete girders 6 feet 6 inches deep and 3 feet 6 inches wide being each between the roadway and the cantilevered walks.

Each of the cantilever portions of the main girders, about 21 feet out from the abutments, has of course its reinforcement, of thirty 1½-inch Johnson corrugated bars in four vertical rows, near the top, while the 58-foot girder portion has its twenty-four 1½-inch bars

in three rows near the bottom, these overlapping the cantilever-bars by about 6 feet. The point of maximum shearing-stress, where the girder and cantilever meet, has thirty short 1¼-inch bars inclined downwards towards the centre of the bridge, connecting the reinforcements of the two portions. Each cantilever is anchored by an extension of itself back of the abutment face and carried down to nearly its foundation-level, these being connected by a floor on which, and behind the abutment wall, the earth of the approach rests, giving great weight. This part of the work is strongly reinforced with light rails and 1¼-inch rods, the former being vertical in the back part of the 3 feet 6 inches work and horizontal in the floor just mentioned, while the rods slope from the top of the cantilever, just over the face of the abutment, down to the back of the structure, thus strengthening the anchorage.

The bridge-floor is 13 inches thick and is reinforced with transverse I beams which extend so as to carry the footway. They are hung from the girders by pairs of 1-inch tie-rods about 6 feet apart imbedded in their centres and anchored just below the coping to a steel plate. The floor is designed to carry a live load of 200 lbs. per square foot, but this is, of course, trifling in comparison with the dead load of the bridge, amounting to about 3 cubic yards of concrete and steel per lineal foot of the span.

The forms were removed 3 months after the concrete was set without any settlement.

The girders and floor contain about 200 and the abutments 800 cubic yards of concrete, the whole structure complete costing $17,500 (£3,645 16*s*. 8*d*.).

C. O. B.

Curves for Reinforced Arches. DANIEL B. LUTEN.

(Engineering Record, New York, 14 April, 1906, pp. 482–3.)

This article shows how the employment of reinforcement enables the curve of equilibrium, viz., a transformed catenary in the case of earth loading to a level top, to be brought within a lighter arch than if unassisted material were used. The Author shows, by diagrams, arches varying as to kind of curvature in the extrados and intrados, and comes to the conclusion that the greatest economy is attained when the inner curve is a mean between a circular segment and an ellipse, and the outer curve a circular segment, and the methods of locating their several centres and radii are explained. The article then proceeds to show the position and proportions of the corresponding reinforcement, and examples of bridges so constructed are given.

C. O. B.

Reinforced-Concrete 146-*Foot Arch at Playa del Rey, California.*

(Engineering Record, New York, 31 March, 1906, p. 419.)

A short but interesting article on a very handsomely designed foot-bridge, as the illustration shows. The rise is 18 feet, and there are three elliptical arch ribs, each 14 inches thick and 24 inches deep at centre, including the floor thickness, which is 4 inches. The width of the bridge is 19 feet. The ribs are reinforced by four $3\frac{1}{2}$ by $2\frac{1}{2}$ by $\frac{1}{4}$ inch angles, one at each corner, connected vertically by $1\frac{1}{2}$ by $\frac{1}{4}$ inch bars, and by three 24-lb. rails one over the other. There are also transverse beams similarly armed. The 4-inch floor is reinforced by a network of $\frac{3}{8}$-inch bars 5 inches apart. The bridge was tested with a load of $3\frac{1}{2}$ tons per square yard. C. O. B.

Ventilating the New York Subway.

(Engineering Record, New York, 7 April, 1906, p. 439.)

The purity of the air in the New York Subway has been proved by official reports, but the evil arising from the heat due to the electric operation of the trains remains, the article reviewing what is being and proposed to be done to mitigate it. A recent report by Mr. G. Rice states that about 83 per cent. of the energy furnished from the power-station appears as heat in the subway, and, after allowing for what is dissipated through the floor, walls and roof, and escapes through the station passages, he estimates that the effect of the remainder is to increase the temperature by 12° to 20° F, according to the season of the year.

Two methods of removing the air, which Mr. Rice prefers to be done midway between stations—for which reasons are given—have been tried and found practicable. One is to provide balanced louvres, opening outwards only, which, when a train approaches, will open by the pressure of air produced, and shut again after the train passes, the vacuum ensuing inducing fresh currents through station openings. By this it was found that 5,000 to 20,000 cubic feet of air per minute, according to movement of trains, were discharged through 100 square feet of louvres. This being considered insufficient in summer, the second method of fan-chambers combined with the above is proposed, the fans being run on summer nights only, the train movements at other times being considered sufficient. The necessary chambers are to be made larger than actually necessary for ventilation, so as to serve for extra exits to the street in case of accident.

The question of addition to these improvements by the evaporation of water, refrigeration, or the absorption of the heat by disposing water through the subway in some manner, is also discussed, but further experiments will be made before any plan is finally decided on. C. O. B.

Construction of the Gallitzin Tunnel, Pennsylvania Railroad.

(Engineering Record, New York, 5 May, 1906, pp. 567–8.)

The description of the construction, generally, of this concrete tunnel, though interesting, is not sufficiently remarkable to call for abstract, but the concluding part of the article, dealing with a successful solution of the perplexing problem of ventilation, is worthy of special notice.

After completion of the tunnel, which is a single one about 3,600 feet long for West-bound trains only, on a rising grade of 1 in 100, it was found that the smoke and gases were so dense that train men sometimes became unconscious; a ventilating apparatus, invented by Mr. C. S. Churchill, of which illustrations are given, was adopted.

It consists of a sheet-iron hood about 50 feet long, enclosing a track (*sic*) and having an inner surface coincident with the soffit of the tunnel arch and walls. The outer surface is converged from the outer end of the hood to the portal of the tunnel, and a Sturtevant blower is installed at the end of the hood on each side. These deliver air through it to the tunnel portal, where a narrow opening in the inner face of the hood permits the blast to be forced into the tunnel nearly parallel with its axis. As soon as the locomotive enters the tunnel, the fan is started, and the large volume of air, forced into the narrow space between the train and the tunnel-lining, drives the smoke and gas in advance of the locomotive, so that their effects are not felt. The arrangement is considered efficient and satisfactory.

C. O. B.

Discussion of Formulas for Concrete Beams. H. Goldmark.

(Engineering Record, New York, 31 March, 1906, pp. 420–2.)

The rapid adoption of reinforced concrete as girders, as in other forms of construction, has given a special interest to theoretical as well as practical considerations of the subject. It is in the former respect that this Paper is valuable.

After pointing out the adaptability of reinforced-concrete beams to theoretical determinations as to dimensions, the Author sums up his introduction by stating that two different assumptions are made: (*a*) that the steel carries all tensile stresses; (*b*) that the concrete takes part of them. The notation being given as generally identical for all the formulas giving the moment of resistance of cross-section, the following are fully discussed, viz., under (*a*) Thacher's, Sewall's, Buel's, Von Emperger's, Wentworth's, Hennebique's, Coudron's, Talbot's and Goldmark's, and under (*b*) Johnson's and Hatt's. The subject is further discussed in the *Engineering Record* of the 5th May, 1906, pp. 568–70, by Mr. Leonard C. Wason, who in addition to the formulas mentioned by Mr.

Goldmark, refers to those of Burr, Warren, Kahn, and Wason, and summarizes the various results with a given beam in two tables giving bending-moment, breaking-load, area of steel, stress in steel; distance from top to neutral axis, arm of moment of resistance, and arm as percentage of efficient depth. There are some considerable differences.

C. O. B.

Detailed Cost of Hand-Mixed Concrete Work.

FRED. R. CHARLES.

(Engineering Record, New York, 31 March, 1906, p. 422.)

These notes will be of great value to contractors and others in estimating. They give the cost in detail of such work at five different works, under varying conditions, which are stated. They were all bridge-piers under and over water, except one which was a dam of reinforced concrete. The details given are:—(1) total quantities; (2) cost of cement, sand and stone separately; (3) cost of lumber (timber); (4) tools; (5) pumping; (6) setting forms; (7) mixing and placing; and (8) daily rates of wages. The total cost per cubic yard varied from \$5·58 (£1 3*s.* 3*d.*) to \$7·23 (£1 10*s.* 1½*d.*), the daily wages being \$1·75 (7*s.* 3½*d.*).

C. O. B.

Legal Requirements for Concrete Constructions.

RUDOLPH P. MILLER.

(Engineering Record, New York, 28 April, 1906, pp. 538–43.)

This Paper, read before the Concrete Association and the National Association of Cement Users by the Chief Engineer of the Bureau of Buildings, New York, carries authority. After urging flexibility in regulations in order to meet new conditions as they arise, such, for instance, as investing inspecting officers with sufficient discretion, and only laying down fundamental principles, the Author quotes from the regulations of the Building Code of New York as regards tensile strength of natural and Portland cements in air and water, after definite periods, but thinks that samples should be tested for soundness as well as strength, and that the testing should be at some reputable laboratory. As to concrete, he goes on to show the variety of proportions in general use according to the purpose required, and hence the difficulty of prescribing standard mixtures. The New York and the Philadelphia regulations are then quoted as regards modulus of rupture, ultimate compressive strength and percentage of absorption.

But the important part of the Paper is that concerning reinforced concrete, owing to its recent extensive use, especially in

the States, New York City being the first municipality to prescribe regulations in connection with it. These, combined with those of the National Board of Fire Underwriters, as to the ultimate stresses per square inch, include the following:—

	Working-Stress. lbs.	Ultimate. lbs.
Extreme fibre stress of concrete in compression	500	2,000
Shearing stress in concrete	50	200
Concrete in direct compression	350	..
Tensile stress in steel	16,000	..
Shearing " " "	10,000	..
Adhesion concrete to steel	50	200

Variations from these in the regulations of other cities and other requirements are given and commented upon.

The alleged vulnerability of concrete to fire is then considered, and determined to be practically non-existent, except when green, thus containing too large a percentage of uncombined water, which, being converted into steam, causes rupture. The code, as to this particular, of the National Board of Fire Underwriters, is given in full.

The Paper concludes with a valuable paragraph on the weathering of concrete, the New York provision for freezing-tests being quoted.

C. O. B.

Economical Design of Reinforced-Concrete Floors for Fire-resisting Structures. J. S. Sewell, M. Am. Soc. C.E.

(Proceedings American Society of Civil Engineers, New York, December, 1905, pp. 625–59.)

The object of the Paper is to present formulas combining the simplicity of purely empirical ones and the accuracy attainable by the more rational ones; with considerations relating to applying them to evolve designs of minimum cost. The writer proposes a formula in which the resisting moment of the reinforced-concrete beam is expressed as the moment of the stresses in the steel about an axis passing approximately through the centroid of the stresses in the concrete, but the lever arm is assumed as a constant percentage of the depth of the steel below the upper surface of the beam.

If A is the total sectional area of the steel, d the depth of the centre of gravity of the steel below the upper surface, T the unit stress in the steel, h a constant and M the resisting moment of the beam, then $M = h\,d\,A\,T$. To obtain suitable values for h, the form of the stress-strain diagram of the concrete in compression has to be found. From published tests of the Watertown Arsenal, the Author concludes that although for very rich mixtures the stress-strain curve does not differ much from a straight line, for leaner mixtures it does so very materially. The tests were grouped according to ultimate strength, and these groups were subdivided according to the age and composition of the concrete; average values of the elastic deformation in each group for different loads were obtained,

and curves drawn in each case. The curves were found to differ appreciably from a straight line, indicating a decreasing modulus of elasticity under increasing loads. The writer takes the stress in the concrete, when that in the steel reaches the elastic limit, as 80 per cent. of the ultimate strength of the concrete. It was found that the areas between the curves above referred to and the axis along which the deformations are plotted, up to 80 per cent. of the ultimate strength of the concrete, averaged 57 per cent. of the rectangular area bounded by the co-ordinates of this point and the axes; and the distance of the centre of gravity of the areas from the natural axis averaged 64 per cent. of the ordinate of the 80 per cent. point referred to above.

The value of h, obtained by finding the moment of the stresses in the cross-section on the above basis, is 0·856, assuming the ultimate strength of the concrete to be 2,500 lbs. per square inch, and the ratio of the modulus of elasticity of the concrete in comparison to that of the steel in tension to be $\frac{1}{15}$, and the elastic limit of the steel to be 45,000 lbs. per square inch; if, instead of the stress-strain curve taken, a straight line be assumed, the value of h is 0·865; and if a parabola with its vertex at the neutral axis be assumed, h is 0·84. If therefore h be taken equal to 0·85 little error is introduced.

With the same assumption the area of the steel is 0·01 db, where b is the breadth of the beam; if the straight line distribution of stress be assumed the area of steel is 0·009 db; and with a parabolic distribution it is 0·012 db. But it does not follow that either values are necessarily the most economical in first cost. The writer then proceeds to find the most economical ratio of the area of the steel to that of the concrete, based on the relative prices of the two materials, both in the case of rectangular beams and T beams. He shows that for economy A should not be greater than $\frac{bd}{p}$, where p is the ratio of the cost of equal volumes of steel and concrete. He advocates the use of web members, arranged as nearly as possible along the lines of the tensile web stresses, and attached rigidly to the horizontal reinforcements, in order to transmit the stress between the tension-bars and the concrete. These web members should increase in number as the shear increases.

A. W. B.

Fire Tests in a Model Theatre. HARDER.

(Gesundheits-Ingenieur, Munich, 20 December, 1905, pp. 565–9.)

Under the auspices of an influential committee of the Society of Austrian Engineers and Architects a series of practical experiments have been carried out in Vienna in a model theatre constructed to a scale of one-third the actual size, adapted for an audience of about 1,500 spectators. The theatre was formed of Monier concrete, and plans and sections are given to show the details of construction. The

stage was 24·6 feet wide, 19·68 feet deep, and 25·26 feet high. The proscenium opening was 11 feet wide by 8·53 feet high, and the auditorium 18·04 feet wide, 22·96 feet long, and 15·42 feet high, provided with a gallery having an iron railing round it and two external staircases. The outer wall of the pit was fitted with glass windows to enable observations to be made of the progress of a fire on the stage. The stage was designed with three exits, and various kinds of iron doors were used, as also some of wood protected with sheet iron and covered with asbestos. Galleries were made on either side of the stage at a height of 9·35 feet above it, and a working floor for scenery at a height of 19·68 feet. Various shafts for ventilation purposes and skylights fitted with shutters were arranged above the stage and the auditorium, and a regular fireproof iron curtain fixed in iron grooves was fitted to the proscenium-opening. Numerous thermometers, pyrometers, manometers and arrangements for testing the air were introduced and the scenery and fittings were all reproduced to scale and saturated with petroleum, in order to burn with greater rapidity. In all thirty-one experimental conflagrations took place in the presence of experts with results which are described. The importance of providing ample exits for the products of combustion above the stage is insisted upon, and it is stated that in conjunction with a suitable iron curtain in the proscenium-opening, they afford the best possible protection for the safety of the public in the auditorium. The difference in relative proportions even in this large model between the cubic contents and those of an actual theatre is very marked, being only the twenty-seventh part of the total. Some of the tests were directed to ascertain the results with various modes of illumination during fires.

G. R. R.

Structural Lessons of the San Francisco Earthquake and Fire.

(Engineering Record, New York, 5 May, 1906, p. 550.)

A short article discusses the best provision to be made in the case of the construction of tall buildings, which shall be safe against earthquake and fire. Foundations are dealt with, and the necessity of properly anchoring the superstructure to them is urged. It is decided that the steel cage framework is the best, and can be made absolutely safe by the adoption of a few modifications of standard practice, such, for instance, as the provision of diagonal rods bracing the interior columns. The wall columns are usually sufficiently braced by the hollow-tile wall-construction, which, when 12 or 15 inches thick, adds enormously to the stiffness of a building. Reinforcement is also dealt with as a factor both as regards foundations and superstructure. The article points out that in such instances, the engineer rather than the architect should be consulted, the duty of the latter being limited to the design of the general scheme and to clothing the skeleton with its appropriate outside embellishment.

Departing from the subject of its title, the latter part of the article refers to the modern practice, unthought of when many city buildings were put up, of mining the subsoil with subways, such as is going on now extensively in Chicago, and the precautions which may be necessary to preserve the buildings there in consequence.

C. O. B.

Comments of Californian Engineers on the San Francisco Earthquake and Fire.

EDWARD M. BOGGS, PHILIP E. HARROUN and STEPHEN E. KIEFFER.

(Engineering Record, New York, 5 May, 1906, pp. 558–60.)

Amidst the sensational accounts of tottering buildings and blazing fires, these practical observations of trained experts come as a relief. Mr. Boggs, in an illustrated communication, states that fully 95 per cent. of the property loss in the city was due to the fire; as to the earthquake, the greatest destruction was to those buildings founded on made ground, especially when a crust of firm ground had been made over mud. Unfortunately, a considerable part of the metropolitan district is so situated. It is a well-known fact that the shore-line of San Francisco Bay some 60 years ago was many blocks inland from the present water-front, and a subsidence of several feet occurred over a wide area. Well-constructed buildings on pile foundations, however, in this locality stood well. In the hilly parts, where bed-rock exists at or near the surface, scarcely any damage was done. The superiority of steel frame construction for tall buildings was manifest, the practical safety of the Claus Spreckels building, 310 feet high on a lot only 75 feet square, being a proof. Underground tramway-conduits are condemned, both earthquake and fire tending to close the slot, and the difficulties of restoration are much greater than in the trolley system. The unchecked fire through breakage of water-mains is referred to, and it is stated that probably these breakages were chiefly where they had been laid on made ground. The Author points out generally how, in rebuilding, these and other defects should be avoided, recommending reinforced concrete, sheet-metal, or even terra-cotta, for chimneys in preference to stone or brick; a great number of chimneys of these latter materials, where unbraced, having fallen and damaged the buildings to which they belonged.

The other communications are corroborative in character, all preferring the steel cage construction, but admitting that well-built brick and stone edifices stood well, notably the Palace Hotel, of which the brick walls survived both calamities.

C. O. B.

Vibration of Tall Buildings.

(Engineering Record, New York, 28 April, 1906, p. 522.)

In connection with the earthquake at San Francisco, the tests on record of the vibration of tall structures under wind-stresses, which are extremely rare, and their relation to earthquake-effects, are reviewed. Some experiments were made, 8 years ago, during a wind-storm of 60 to 70 miles per hour at Chicago, in a building of sixteen stories, a plumb line being let down in a stair-well, with its movements recorded; and the results are given, ½ inch from the perpendicular being the maximum variation. The conclusion arrived at in the article is that it is certain that the steel cage framing used in the better class of buildings has demonstrated its suitability for a city exposed to earth-tremors. The subject was discussed in the *Engineering Record* of the 24th March, 1894, and the 17th June, 1899, and the description of the Spreckels steel cage building in San Francisco, which was injured only by fire, was given in the issues of the 9th and 16th April, 1898.

C. O. B.

Large Steel Vault.

(The Engineer, London, 3 August, 1906, p. 128.)

A steel treasury has been built for the Royal Bank of Scotland by Messrs. Chubb and Sons' Lock and Safe Company, London, which is probably the strongest in existence. The walls, roof, and floor consist of a series of 2-inch slabs of steel which are riveted and bolted together so as to make one continuous piece. Each slab weighs 1 to 2 tons and is made by riveting together by hydraulic pressure four plates of hard steel. The strength of the room may be said to lie in the plates of Cammell's alloy steel made specially for Messrs. Chubb, its property being that it offers a maximum resistance to drilling. The backing consists of layers of hard and mild steel plates welded together. The slabs are fastened together by the double tongue and groove method, which effectively conceals the joint, also on the outside a connecting bar is riveted on to one slab, whilst bolts, passing from the inside of the slab to be joined to it, are screwed into it. The floor is covered with pressed rubber tiles. The outer door-plate is a slab of Harveyed armour plate 4½ inches thick and weighing 2½ tons, and it has been tested by firing a 6-inch naval gun propelling a 100-lb. nickel-steel shell against it at a range of 50 yards. There is an entire absence of all spindle- or key-holes in the door. Twenty Chubb diagonal bolts are secured by a triple time lock, a keyless combination lock, and a special anti-explosive lock protected by a heavy manganese-

steel casting within the room. The hinges are adjustable, and are mounted on ball bearings which enable the door to be moved with comparative ease. A. W. B.

Effect of the Vienna Sewage on the Danube. Dr. Ernst Brezina.

(Zeitschrift für Hygiene, Leipzig, vol. liii, part 3, pp. 369–503.)

Some account is given of the work of Frank, Prausnitz, Schlatter, Pettenkofer and others, sixty-nine in all, dealing with the pollution of the Spree, Isar, Limmat and many other rivers, and tables of analyses by Heider are quoted to show the composition of the water of the Danube at various points. The results of the microscopic examination of the sediments by Heider are specially mentioned, as few other investigators have undertaken such searching tests of river-deposits. The Author considers the polluting substances in rivers either as solid, suspended, or as dissolved matters, and refers specially to the changed views brought about in recent years by modern biological methods of research. After an account of what had been done with respect to the investigation of the pollution and self-purifying powers of the Danube, the Author states that it appeared advisable to undertake a thorough examination of the river, and he prefaces his investigation with a brief account of its chief hydrological features. It is pointed out that the Danube Canal cuts off an important bend of the river, and traverses the city of Vienna with many windings; its total length is nearly 10½ miles. The river is obstructed by numerous sandbanks and small islands, and its course is very tortuous. Great difference in volume occurs at various periods of the year, and when the snow is melting. Attention is called to the tributaries, which are, however, not of much importance. The sources from which the water is derived are discussed, as also its composition and the chief mineral salts present in it. The results of numerous tests are tabulated. A full account is given of the sewerage of Vienna, and of the composition of the sewage-water, with many analyses set forth in tables and graphic diagrams. The sediment was examined chemically and microscopically, and full bacteriological tests were made. The water was passed through fine sieves to study the suspended impurities. A detailed examination was made of the bed of the river, and of the matters deposited in various places. It is asserted that the self-purification of the Danube is carried on in two different ways, by mechanical means and by chemical-biological processes, and it is stated that whereas previous inquiries had only established the probability of biological self-purification, the Author's investigation has demonstrated the certainty of this action. It is, however, chiefly one of theoretical interest, since the mechanical processes of purification are all sufficient. It may further be assumed that the Danube suffers no injury from the discharge of the Vienna sewage-water, since the relative volume of the river-

water is at all seasons so considerable that the amount of dilution is sufficient to do away with any nuisance, and in the summer season when putrefactive changes are most liable to be produced, the volume of water is generally very large. The requisite precautions to be adopted should be the retention of the grosser floating and suspended impurities, and the discharge of the sewage through numerous outlets over as wide a range as possible.

G. R. R.

Pollution of the Lahn and the Wieseck by the Giessen Sewage-Water. Dr. K. Kisskalt.

(Zeitschrift für Hygiene, Leipzig, vol. liii, part 2, pp. 305-68.)

The sewage of Giessen, apart from the fæcal matters, flows either direct into the Lahn or into the tributary rivulets, passing through the town. With the exception of certain brewery-refuse, the sewage is wholly of domestic origin. The population is 28,000 and the daily water-supply amounts to 17·6 gallons. The solid fæcal matters are discharged into cesspits, the contents of which are from time to time emptied and removed, but a few of the cesspits have overflows into the sewers. The river, before it reaches the town, has a course of about 56 miles, and its average volume on passing the town is estimated at 682 gallons per second. Before reaching Giessen the Lahn receives the Marburg sewage. The Wieseck has a flow of about 15½ miles before its entrance into the town, and whereas the Lahn is separated almost entirely from Giessen by a railway-embankment, the Wieseck flows straight across the town; the volume of water in the latter is relatively small, but it receives nearly the whole of the sewage and is greatly polluted; it subsequently flows into the Lahn just outside the town. Numerous experiments are recorded and the results are set forth in tables. It is stated that the water was submitted to every possible test in respect of purity and pollution to which river-water could be subjected. Among the general conclusions it is pointed out that the composition of pure and polluted rivers depends on the temperature and the volume of the water. An excellent quantitative test of existing decomposition is furnished by the transparency of the water (absorption of light) and in the same way the determination of the amount of ammonia, free oxygen, and the number of germs present, gives reliable results, while less dependence should be placed on the percentage of sulphuretted hydrogen and nitrites found in the water. The results obtained are indicated in a series of graphic diagrams.

G. R. R.

Dredging-Plant for India.

(The Engineer, London, 13 July, 1906, pp. 34–8.)

One of the largest dredging-vessels yet produced in this country has been built to the order of the Indian Government by Messrs. W. Simons & Co., and is destined for special work in the Bengal Presidency. It is a suction-pump, triple screw, canal-embankment dredger, designed specially for opening up new waterways and improving the depth of shallow canals or rivers, it being able to cut a canal or channel 40 feet wide at the bottom and deposit the material on or beyond the banks of the waterway. Its length is 250 feet, beam 45 feet and depth 18 feet; it has three complete bows, thus forming for a length of about 35 feet back, two open wells each about 8 feet 6 inches wide. A framework in each of these carries a length of suction piping, to each of which are attached two nozzles; also shafting and gear for two rotary cutters arranged to work in advance of the suction nozzles for disengaging the clayey material which would otherwise be unsuitable for suction-pump dredging. Each suction-frame is also provided with a system of water-jets delivered under high pressure for agitating compact sand not requiring the rotary cutters. Water for the jets is supplied by two special centrifugal pumps in series, driven by an enclosed high-speed compound engine. Each pair of cutters is driven by bevel and spur gear from an independent four-cylinder tandem compound engine placed on deck at the edge of the wells. The cutters are of cast steel and are very massive in construction. Each suction-frame is controlled by independent hoisting-gear driven by two-cylinder engines; and when not at work the frames, pipe, and cutters are hoisted clear above water-level. The dredge has two mooring-horns at the bow end for the purpose of mooring whilst at work. The two centrifugal sand suction-pumps, situated a little forward of midship, have a nominal dredging capacity of 4,000 tons of sand per hour from a depth of 20 feet, and are specially constructed with wide spaces to admit the passage of large pieces of debris. Each suction-pump is driven by an independent set of vertical triple-expansion engines of 900 I.HP. The pumps deliver the material direct through a floating pipe-line, 42 inches in diameter and 600 feet in length, which is supported at its extremity by a terminal pontoon at a height of 20 feet above water-level. The pipe-line leaves the dredger at the stern, and there is a special swivel connection so arranged that the pipe-line can be connected directly aft or to a range of 90° on either side of the centre of the dredger. The floating discharge-pipe consists of ten circular pontoons, each carrying a 60-foot length of 42-inch pipe coupled together by special flexible connections.

The vessel is propelled by three sets of vertical compound condensing engines, each driving a propeller with four blades, and is capable of travelling at a speed of 8 knots per hour—steam is provided by four Babcock and Wilcox water-tube boilers.

There are on the dredger and pontoon as many as forty separate self-contained engines, and one main condenser is provided to take the steam from them all. An evaporator for providing fresh water, a refrigerator-plant, electric-light instalment, including searchlights, a workshop, a telegraph from the bridge to all parts of the vessel, and a telephone connection to the terminal pontoon are included in the equipment.

A. W. B.

Levee and Drainage-Works at Memphis, with a Pumping-Plant of Unusual Design.

(Engineering Record, New York, 21 April, 1906, pp. 496–9.)

Very extensive works for the prevention of floods and sewage-overflow are described but have no special interest; the pumping-plant, however, has some remarkable features. It has a normal capacity of 40,000,000 gallons per 24 hours, and consists of three centrifugal pumps. Two of these, one a 20-inch and the other a 24-inch, are placed on the floor of the pump-room. The former is directly connected to a 150-HP. three-phase Westinghouse induction-motor, the unit operating at 495 revolutions per minute, and the latter to a 175-HP. similar motor, the unit running at 435 revolutions per minute. The third pump is an 8-inch horizontal one, which is placed in the bottom of an 8-foot by 8-foot chamber adjoining a well into which the relief-main from the 48-inch sewer, described elsewhere in the article, discharges. This pump is directly connected, through a vertical shaft, to a 50-HP. three-phase induction-motor on the floor of the pump-room. Power to work the motors is purchased. The motors driving the large storm-water pumps each have a rated capacity 30 per cent. in excess of that required for normal conditions. Adjoining the station is a natural depression, which has been enlarged until it has a storage-capacity of about 4,000,000 gallons, and an overflow from the suction-well enables any flow in excess of the capacity of the pumps to be diverted there, and drawn from it as the pumps overcome the quantity of flow. It is also of use when either of the pumps is disabled. The contract cost of the plant was as follows. The 8-inch pumping outfit, $1,635 (£340 12*s.* 11*d.*), for the 20-inch outfit, $4,250 (£885 8*s.* 2*d.*), and for the 24-inch, $5,100 (£1,062 10*s.*). The whole of the pumping-plant and necessaries, including the building, cost $25,000 (£5,208 6*s.* 8*d.*).

C. O. B.

Largest Tube in Existence for Irrigation Purposes.

E. AMONTILLADO.

(La Nature, Paris, 9 June, 1906, pp. 21–2.)

The siphon of Sosa near Monzon in the province of Huesca in Spain is stated to be without doubt the largest tube yet constructed. It is formed of armoured concrete and attains a total length of 3,340 feet, being destined to discharge 7,700 gallons per second from the Canal of Aragon and Catalonia for the irrigation of some 262,000 acres in the valleys of the rivers Sosa and Rivabona. The siphon is composed of two huge tubes laid side by side on the surface of the ground, the internal diameter of each being 12·46 feet, and these tubes have to bear an internal pressure due to a head of 91·85 feet. The method of conveying the water by means of a siphon in lieu of constructing an aqueduct was selected as being the cheaper system, after a competition in which the present plan, the design of Don José E. Ribera, who erected the Maria-Christina bridge at Saint-Sebastian, also a work in reinforced concrete, obtained the prize. It is stated that the work was carried out with extreme rapidity, and was opened by the King of Spain on the 2nd March of the present year. Until now the largest concrete tubes were those 10·82 feet in diameter at Champs and Romanche in the Department of Isère. Illustrations are given showing the siphon partly constructed, and the wooden shifting centres used for the formation of the tubes in situ.

G. R. R.

Powdered Coal-Firing for Steam-Boilers.

GEORGE C. MACFARLANE.

(Engineering and Mining Journal, New York, 12 May, 1906, p. 901.)

In this article, on what in an editorial note is described as a highly efficient and economical method of burning coal, possessing many of the advantages of gas-firing without some of its disadvantages, the Author points out the conditions necessary to success, as indicated in cement-making practice where coal-dust firing is employed on a large scale. In burning powdered coal with an air-blast, perfect combustion, with a consequent almost total absence of smoke, is obtained; and as but a small excess of air is required, the furnace temperatures are higher, and proportionally less heat is carried away in the chimney-gases. In the note referred to, the possibilities of coal-dust firing in many kinds of metallurgical work are said to be so striking that it is a cause of wonder why this way of burning coal

has not obtained a footing in that industry. It is added that an improved method of dust-firing, of which something will doubtless be heard before long, has recently been tried experimentally with highly promising results.

The coal, after being dried and crushed, should be ground till 95 per cent. of it will pass through a 100-mesh sieve. All conveyors and elevators should be enclosed in steel casings, and not more than sufficient for a 24-hour run should be kept in the bins. Unless exceptionally free from incrusting matter, the boiler feed-water should be purified, and the boiler be cleaned frequently; because, if any thickness of scale be allowed to form, the intense heat will soon burn the tubes. The boiler-settings should be arranged so that the mixture of coal and air leaving the nozzles may have 12 to 15 feet of unobstructed travel before encountering any bridge or baffle walls. It will be necessary, with most types of boilers, to place a fire-brick retort, or combustion-chamber, 5 to 8 feet long, in front of the boiler, a portion of the regular front being cut away to make a connection with the mouth of the retort. These retorts may be built on trucks to allow of their being rolled back out of the way. The advantage of an auxiliary combustion-chamber is that the mixture of coal and air from the nozzle of the blast-pipe has a chance to ignite and expand into a mass of flame before entering the fire-box. When the free travel of 12 to 15 feet is given, all that is necessary is to blind the grates with fire-brick and to tap the blast-nozzle just above the fire-doors. The blast is ignited at starting by a small wood-fire a few feet from the nozzle. After the bricks have become heated they will be hot enough to re-ignite the blast after a shut down of an hour or more. A fuel-mill for drying and grinding the coal would, in the Author's opinion, not be economical where the daily consumption of coal averages less than 25 tons, unless coal be exceptionally high in price. The Author gives an illustrated description of the dust-firing plant at the Burt Portland Cement Works at Belleville, Mich., where there is a battery of five 400-HP. boilers. The total power to work the complete plant is about 120 HP. About 145 cubic feet of air are required to burn 1 lb. of coal, and when in normal operation the chimney-gases show 1 to 1½ per cent. of free oxygen. In the powdered form ½ lb. less coal per horse-power is required, a gross saving of 18 per cent.; but as 1½ per cent. is required for drying and 5½ per cent. to generate power for crushing, pulverizing and burning, the net saving is about 11 per cent.

G. G. A.

Smoke-Prevention. ALBERT A. CARY.

(Engineering Record, New York, 21 April, 1906, pp. 514–6.)

This suggestive address to the New York section of the Society of Chemical Industries deals with the subject after communication with the smoke-commissions of several cities, and the study of several smoke-ordinances. The conclusion is that smoke-depression depends on, (1) intelligence in the boiler-room; (2) and (3) proper design of the grate and of the furnace.

The Author insists on the importance of more intelligent firemen, who should be required to pass examinations and hold licences, pointing out that such improvements mean higher wages but lower fuel- and repair-bills, and he adds that the employment of automatic stokers by no means dispenses with the intelligence required.

Under the head of grate-surface design, the address deals with the necessity of fixing the area according to the quality of the fuel in use, and incidentally gives the following proportions of combustion per square foot of grate-surface for boilers developing their rated horse-power. Anthracite 15 lbs., semi-anthracite 16 lbs., semi-bituminous 18 lbs., eastern bituminous 20 lbs., and western bituminous 30 lbs., the two first being steam sizes. The chemical reasons for these divergences are fully discussed, as also the question of space between the bars of the grate, etc.

A large portion of the Paper is devoted to furnace-design, and its extreme importance when coal carrying over 15 per cent. of volatile matter is used. The question of testing the density of smoke by the Ringelman chart and the improvements made by the late Mr. Bryan Donkin are referred to.

Perhaps the most important and practical part of the address is the last third of it, which deals with the scientific methods of hand-firing and the great economies attained thereby, and it concludes by a reference to the washing method of smoke-prevention by means of a spraying-chamber through which the products of combustion are made to pass on their way to the chimney.

C. O. B.

Transporter-Cranes at Purfleet.

(The Engineer, London, 20 July, 1906, pp. 70–1.)

The ferro-concrete pier recently erected at Purfleet is at present equipped with two rapid-working hydraulic transporter-cranes with grab-buckets. The cranes are designed for lifting the coal from a steamer and delivering it either into a barge on the river side of the

steamer, into a barge on the land side of the pier, or into trucks running on rails on the pier beneath the cranes.

The cranes are strongly braced steel structures, each having four legs carried on carriages, supported by two double flanged rollers running on rails the full length of the pier. The gauge of the rails is 28 feet and the wheel-base 24 feet. At a level 32 feet above the pier is a track on which runs a four-wheeled trolley carrying the sheaves over which work the wire ropes attached to the grab-bucket, the part of the track over the steamer being hinged in the form of a jib, so that it may be turned up out of the way of the masts, etc. The trolley-track gives a total range of 96 feet, 48 feet overhanging the jetty on the steamer side and 14 feet on the barge side. The grabs used are of the Priestman double-rope type of 80 cubic feet capacity. A section of the trolley-track is carried on a weighbridge built into the crane structure so that each grab-load of coal can be weighed on its way from the steamer to the barge or truck. The lifting, lowering, and traversing motions are all carried out by means of hydraulic cylinders fitted with rams and multiplying sheaves working with wire ropes. The cylinders are placed on the upper part of the crane-frame. The hinged jib is lifted and lowered by means of a hydraulic cylinder fixed vertically on the front of the driver's cabin. The cranes are moved along their rails by a three-cylinder rotary engine. The hydraulic pressure is 750 lbs. per square inch, and the water is conveyed to the cranes by armoured rubber hose connected to hydrants on the pier. The cranes were designed for a capacity of 50 tons of coal per hour each, but this speed can be considerably exceeded.

A. W. B.

Frahm Speed-Indicator. FRIEDRICH LUX.

(Annalen für Gewerbe und Bauwesen, Berlin, 1 July, 1906, pp. 1-9.)

Some account is given of the phenomena due to resonance, and it is shown that Mr. Frahm of Hamburg, after many experiments, has been successful in turning this property to useful account. Steel rods of uniform size and thickness, and of various lengths, firmly held at one extremity and loaded slightly at their free ends, vibrate in accordance mainly with their length and with the weight attached to them. For use in the Frahm indicator a series of rods or tongues, formed of the best watch-spring steel, inserted rigidly in a metal base or socket, and having the upper end bent at right angles, are weighted at the bent end by the insertion of varying quantities of solder into the elbow. These tongues, with a width of 0·118 inch, a thickness of 0·0097 inch, and a length between 1·57 and 1·96 inch, will vibrate 20 to 120 times in the second, equivalent to 1,200 to 7,200 vibrations per minute. By the use of thinner

and longer tongues, or shorter and thicker ones, it is possible to extend indefinitely these numerical results. If a series of these teeth are mounted side by side in the form of a comb, with an interval between each of 0·039 inch, giving to every tooth a different length, or a slightly increased weight, it becomes possible to arrange a scale graduated in the number of vibrations due to each tooth, and the number of teeth may be only two or three, or, if necessary, many hundreds mounted in a row. The instrument thus formed may receive its impulses in a variety of ways; it may be in actual contact with the original source of vibration, or it may be coupled with it by a tension-bar or by a pressure-bar. A number of diagrams are given to explain the mounting of the apparatus for indicating rotation and many different kinds of mechanical motions, to all of which it is extremely sensitive. It is being used on the Prussian State railways on ninety of the locomotives to register the speed, and it is stated that this instrument is adapted for the analysis and measurement of an almost endless variety of movements. An interesting fact is that, after over 1,000 millions of vibrations, the action of each tongue remains unaltered.

G. R. R.

High-Speed Centrifugal Pumps. O. E. JØRGENSEN.

(Ingeniøren, Copenhagen, 1906, pp. 111-12.)

For working at high pressures, sextuple compound centrifugal pumps are constructed by Messrs. Sulzer Brothers, Winterthur, in which a series of six pump-wheels are arranged one behind another on the same axle. The water admitted to the centre of the first wheel is thrown out at the circumference into an annular casing, from which it is guided inwards to the centre of the second wheel; and so on in succession throughout the series. Drawings are shown of two constructions for carrying out this arrangement in detail, by suitable modification of the annular casing and intermediate guiding disks. The wheels work just like turbines, and their combined power is the sum of the power of each. They are made of bronze, on a nickel-steel axle, which has its bearings in grease-boxes cooled by a water-jacket.

Diagrams are given from one of these pumps at a mine at Horcajo in Spain, after 1 and after 5 years' continuous work day and night, showing as much as 76 per cent. efficiency at an average speed of 870 revolutions per minute against a constant head of 389 metres in one diagram and 480 metres in the other (1,276 and 1,574 feet). A newer pump at the same place gave 79½ per cent. efficiency at about 1,320 revolutions per minute against 38 metres (125 feet) head; and a sinking pump gave a maximum of 84 per cent. at about 1,025 revolutions per minute against 46 metres (151 feet) head. The diagrams show also the horse-power expended and the

delivery per second. Pumps have thus far been built to work up to 750 metres (2,460 feet) head of water or 75 atmospheres, and there is nothing to hinder their going higher. They are specially adapted for coupling direct to electric motors, owing to their capability of running at the same high speeds. Such an arrangement is now carried out at several mines for underground pumps, where motor and pump are coupled on a vertical spindle, and the whole is lowered down the mine shaft to the depth required, and is supplied with electricity from a power-station at surface. As shown by photographs, the pumping-gear thus occupies but little room in the shaft, and can be drawn up bodily out of the way of blasting.

At the Geneva waterworks a double set of these pumps with runners 1·1 metre (43·3 inches) in diameter, driven direct by a 1,000-HP. vortex turbine, raises 10,000 tønder (305,000 gallons) of water per hour against a head of from 140 metres (460 feet). In Frankfurt Goldstein three 110-HP. vortex turbines with direct-coupled pumps each raise 2,500 tønder (76,000 gallons) under a head of 65 metres (213 feet); photographs are shown of these three sets. At three waterworks in Milan are seven pumps driven electrically; and a new waterworks is being put up, in which three pumps are to be driven by belts from gas-engines at 925 revolutions per minute, each to pump 2,700 tønder (82,000 gallons) against a head of 52 metres (170 feet). The first town in Denmark to introduce these high-pressure pumps for waterworks is Viborg, where a 45-HP. Diesel motor driving by belt is to pump 1,100 tønder (34,000 gallons) per hour against 175 feet head; these works are now in course of erection.

A. B.

10,000-*HP. Single-Wheel Turbine.* ARTHUR GEISLER.

(Engineering News, New York, 29 March, 1906, pp. 352-5.)

This turbine was built for the Seattle and Tacoma Power Company at its Snoqualmie Falls station, 35 miles east of Seattle, Washington. The plant there transmits electric current to Seattle and Tacoma. The height of the falls is about 270 feet. The machinery is placed in a chamber 200 feet by 40 feet by 30 feet, excavated in the solid rock, 250 feet below the surface, and about 300 feet up-stream of the crest of the falls. At the up-stream end of the chamber a vertical shaft, 27 feet by 10 feet, rises to the surface. The middle of this is occupied by an elevator, and the end compartments contain two 7½-foot penstocks. From the down-stream end a tail-race tunnel leads to the lower reach of the river. The first instalment consisted of four six-wheel Doble tangential water-wheels, each of 2,500 HP. capacity, and driving directly three-phase alternators. It was intended to excavate another similar chamber for the second 10,000 HP., but, as a small amount of space was still

available, it appeared that by using a turbine of large capacity the expense of the second chamber could be avoided. The turbine was designed for an effective head of 260 feet and a speed of 300 revolutions per minute. It is a single-wheel, horizontal-shaft machine, of the radial inward-flow type, with usual discharge. The turbine proper has only one shaft-bearing on the side away from the generator, while the latter has two bearings. The wheel is 66 inches in outside diameter, and has thirty-four vanes 9½ inches wide; these extend a short distance beyond the end plate of the wheel on the discharge side, and are curved so as to give the turbine a "mixed-flow" effect. The guide vanes are thirty-two in number, and are integral with the spindles on which they turn. Each spindle has an arm keyed to it, outside the turbine-case, which is finished with a straight rectangular end; the end of each arm fits with a close sliding fit in a cylindrical block; the blocks fit in cylindrical recesses round the circumference of the operating ring. This ring is actuated through a connecting-rod and a shaft by a Lombard governor, and regulates the size of the openings between the guide-blades. The turbine-wheel is an annular steel casting, the radial depth of which is sufficient to contain the vanes, and the shaft, 13½ inches in diameter, is enlarged into a disk to permit of bolting the wheel-ring directly to it. The wheel-ring on the side away from the discharge-pipe is subjected to the supply head, and on the discharge side to a pressure varying from the supply head to the discharge head; therefore there is a tendency for the wheel to move towards the outlet side, which is further intensified by the curvature of the vanes towards the outlet. To counteract this there are openings through the wheel-disk to the discharge, but the resultant thrust is towards the discharge-pipe, and this is balanced by a piston forged as an enlargement of the shaft, and 17 inches in diameter. The two sides of the piston are connected by small pipes to the supply- and discharge- pipes of the turbine respectively, and by regulating the opening of the valve on the former the balance can be regulated. A thrust-bearing takes up any unbalanced pressure.

A. W. B.

Drying of Beet Slices. G. H.

(Teknisk Tidskrift, Stockholm, 1906, Chemical and Mining section, pp. 17–18.)

In a recent pamphlet on "Beet Slices and Beet Pulp," by Messrs. S. Forsberg and Mats Weibull, Malmö, it is pointed out that a Swedish sugar-house, treating annually 800 million kilograms (say 800,000 tons) of beet, turns out half this weight in slices, which as fodder for cattle is about equivalent to three-quarters its weight of raw beet. It is accordingly with advantage that it finds its way back to the beet-grower.

As they come from the diffusers, the soaked slices contain only about 5 per cent. dry matter, which by pressing is brought up to

per cent., made up of 0·1 crude fat, 0·7 crude protein,[1] 6·7 hydrocarbons, and 0·5 per cent. ash. The accumulation of slices during the beet season is stored in silos, where it undergoes fermentation, and becomes what is then known as beet pulp; the retarded acidification is accompanied by the formation of lactic acid. If the decomposition goes too far, the pulp contains too large a proportion of butyric and acetic acids to be good for beasts and milk. Otherwise on an average it contains 9·5 per cent. dry matter, whereof 0·2 is crude fat, 0·9 crude protein, 0·8 ash, and 7·6 per cent. hydrocarbons; the acids of the last constitute 0·5 to 2·0 per cent. Owing to the inevitable decomposition, the stored pulp, in spite of its higher content of crude food-ingredients, is at best only as good as the fresh slices, and often considerably worse.

Drying the fresh slices is recommended as an ideal and thoroughly practicable plan for storing them. Repeated tests made at the Alnarp Agricultural Institute have shown that dried slices from a Swedish sugar-works possess the same properties and composition as good meadow-hay. In this way, almost all losses are avoided, and a particularly valuable fodder is secured.

In connection with these Swedish conditions, reference is made to those obtaining in Germany, where already 146 houses—about one-third of all the sugar-works—have arrangements for drying the soaked slices. Out of 6,000 million kilograms (say 6,000,000 tons) of slices per season from the diffusers, about 42 per cent. is dried, yielding 6 per cent. dry slices. These crumble less, cost less for carriage, and are more valuable as fodder because more wholesome than wet slices and pulp. They fetch 4 to 5 shillings per cwt.; while the cost at the works—including the value of the wet slices, redemption of outlay, and fuel, etc.—is 2½ to 3 shillings. The difficulty in drying on a large scale has been that, if the slices are heated above 100° C. or 212° F., they are rendered indigestible. In Büttner and Meyer's method success has been achieved by the direct action of hot flue-gases on the wet slices; the evaporation from their surfaces absorbs so much heat that they never get hotter than the critical temperature. Drawings are given of a drying-oven three stories high, with fire-place on top, whence the gases pass down through the successive tiers, along with the wet slices, which after pressing are also fed in at the top. In each story is a row of revolving trommels, carrying brushes arranged helically to propel the slices continuously forwards. The heat is greatest at the beginning of their course. The gases and steam are drawn through to the chimney by a ventilator. The dried material is discharged from the bottom of the oven by a creeper. A. B.

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[1] Although Mulder's protein theory, propounded more than half a century ago, met with objection from the outset, the word seems to have been retained as a convenient designation for an indefinite aggregate of carbon, nitrogen, hydrogen, and oxygen, contained in an organic compound. Whether it is here used in this hazy sense, there is no clue for determining.—A. B.

Continuous Drying-Oven. FILIP BERGENDAL.

(Teknisk Tidskrift, Stockholm, 1906, Chemical and Mining section, pp. 38-9.)

For drying green wood of all kinds—saw-mill refuse, peat, white moss, and many other wet substances—a continuous oven has been designed by the Author, jointly with Mr. Tidblad, of which sketches are given. The material is fed continuously by an elevator into the top of the rectangular oven, in which are arranged lengthwise a series of six horizontal layers of endless chains, one above another, travelling alternately in opposite directions, and each dropping its load on the next below, until the stuff reaches the bottom of the oven. Meanwhile an ascending current of hot air from flues beneath the floor of the oven meets the successive layers, and gradually heats and dries the material on them. At the top of the oven a couple of ejectors draw off the moist air, and afford the means of regulating both the quantity of the drying current and the heat of the oven. There is also a blowing-fan for driving air in through the bottom flues; a dynamo drives the travelling chains as well as the fan. The fire-place at the bottom of the oven burns only the worst fuel; if this is sawdust, it is dried in a chamber adjoining the fire-place. If the dried wood is intended for coaling, the surplus uncondensible gases, after the by-products have been saved, can be used as fuel.

A. B.

North-Western Ohio Bottle Company's Factory.

(Engineering Record, New York, 24 March, 1906, pp. 407-9.)

This large building, 142 feet by 149 feet, of Ransome reinforced concrete is not generally of remarkable character, but the construction of the 64 feet by 49 feet furnace room is so, owing to the massive roof-girders and rafters, 65 feet span, 16 feet apart on centres which are made integral with the columns supporting them. The shape of the principal or rafter, which is 18 inches by 40 inches in cross section, is like that of a low-pitched Gothic roof with curves at the peak and at the lower ends, the rise to soffit being 13 feet. The concrete was 1 : 1½ : 3 with Tiger Portland cement and ¾-inch broken stone mixed very wet in a Ransome mixer. The reinforcement was by ten 1-inch bars near the upper surface in sets of two, one above the other, and ten near the lower surface, both carried down to the feet of the columns. These top and bottom chords are connected, similarly to a bridge truss, with five sets of N trussing in coils ¼-inch in diameter, with the verticals 18 inches apart in the slope and 9 inches apart in the arched centre. In the

columns, the truss is isosceles, the bases being 1 foot 8 inches. The pitch of the coils varies from 9 inches at the crown to 18 inches at the haunches, and the rods in them are made continuous by lapping 18 inches at joints, where they are wired together. The rafters are braced by horizontal longitudinal purlins of similar material, but of less dimensions, as to which full information is given. The wall columns have footings 6 feet 10 inches by 7 feet 6 inches, 6 inches deep at outer edges, and 18 inches deep at centre, strongly reinforced. There is much detail about the rest of the building, which in all contains 1,500 yards of concrete and 85 tons of twisted steel, the whole being finished by an average force of thirty men in 70 days.

C. O. B.

Coal-Handling in the Chicago Subway.

(Engineering Record, New York, 31 March, 1906, pp. 414–6.)

The distribution of freight through subways under the principal streets of Chicago, and about 40 feet beneath them, enables coal to be conveyed from the railway-sheds to various establishments, and this article describes the works finished and in hand for its transhipment from railway-wagon to subway-truck, and thence to cellar. At the Chicago and Alton Railroad down-town goods-yard, there are three large rectangular concrete-lined hoppers with their tops just above ground level in the yards. The hoppers are built end to end covering an area of 240 feet by 80 feet, which is covered by an iron roof. Two of the yard tracks are carried longitudinally across the hoppers on transverse steel girders. The hoppers, about one-third of the way down to the subway, have circular concave bottoms, from the centre of which are vertical concrete chutes, lined with steel, 2 feet 6 inches by 3 feet. These extend down to two short inclined chutes built through the arch of a connection with the single-line tunnel subway below; the latter are 6 feet wide by 7 feet 6 inches high in the clear, with a flat floor and arched roof, the 28-inch gauge trucks being of steel 10 feet 8 inches by 3 feet 8 inches inside dimensions, with a capacity of 5½ cubic yards, or 6 tons of coal, of which trains of three to eight cars are handled by an electric locomotive. Turn-outs, or by-passes as they are called, are by separate single tunnels where necessary. The subway-cars are arranged for dumping at either side as required. The inclined chutes are so spaced that all the cars of a six-car train can be loaded at the same time.

The connection for unloading the coal at its destination is exemplified by that built for the new Majestic theatre, which can only be properly understood by reference to the illustrations, but the main principle consists of a pit into which the coal is side-dumped, and a vertical bucket elevator on a strap and side bar link chain, in

a shaft by which the coal is lifted to the basement, where the mechanical plant of the theatre is placed. There is also a chute for discharging ashes from this basement into the subway-trucks for removal.

The Chicago and Eastern Illinois Railroad coal-chutes of the same general character are also described, and a comparison is made between this system of distribution and the old method by conveyance through the streets by teams, both as regards time and public convenience.

C. O. B.

Electric Driving of Winding-Engines. R. DE VALBREUZE.

(L'Éclairage Électrique, Paris, 1906, vol. xlvii, pp. 371, 409, 446 and 485.)

In this Paper the Author describes the different arrangements which have been adopted up to the present time for the application of electric driving to winding-engines in the shafts of pits. The first systems described are those of relatively early date, in which the motors driving the cage-rope are connected directly to the generators in the station, and several examples of these arrangements, as used in different pits both with continuous currents and with alternating currents, are given and their operation fully discussed. An objection to this type of machine is that the sudden variations of load when the engine is started and stopped are troublesome when other plant is also supplied with current from the station, and the next step of progress was made by devising an arrangement whereby the mean power absorbed at the station should be made as uniform as possible. The general solution of the problem is to drive the cage by continuous-current motors, of which the potential difference at the terminals is varied by a suitable auxiliary apparatus, and to place in the derived circuit of the network a battery, or a fly-wheel, to store energy while the engine is at rest and restore it when the engine is working. A corresponding arrangement can be made for the case where three-phase currents are used. The Author gives examples of apparatus of this class, notably the Leonard system for continuous currents, and the Ilgner system for three-phase currents. Various plants where the Ilgner system is in use are fully described, and a table is given showing the principal characteristics of other interesting installations on this system.

Two objections to the Ilgner system are that the double or triple conversion of energy and the friction in the bearings of the heavy fly-wheel lower the efficiency very considerably, and that the initial cost is very heavy on account of the price of the different elements and of the costly foundations rendered necessary for the fly-wheel. In the latest types, therefore, attempts have been made to get over this difficulty by allowing greater variations of speed, thus permitting of a reduction in the weight of the fly-wheel. The Paper concludes

with a description of the Lahmeyer and the Creplet systems, both used with continuous currents, the latter being a modification and simplification of the former.

W. C. H.

Honigmann Method of Shaft-Sinking. ADOLF E. HARTMANN.

(Engineering and Mining Journal, New York, 21 April, 1906, p. 737.)

Of three methods now successfully employed in shaft-sinking through quicksands, the Sassenberg-Clermont, the Poetsch, and the Honigmann, the last is but little known outside the German coal-fields. Yet it has proved to be a very efficient method; and quite recently, in western Germany, seven shafts, varying between 12 feet and 18 feet in diameter, have been successfully sunk by it without noteworthy accident, through sands up to 600 feet thick. The Honigmann method of sinking differs from others in requiring no casing to be built until the shaft has passed completely through the sand to the solid rock. The means used to prevent caving in are, (1) to raise the water-level in the shaft to a certain height above the natural water-level in the quicksand outside, and (2), to increase the specific gravity of the water column in the shaft to about 1·2 by mixing clay with the water. In this way a pressure is obtained which forces the clay held in suspension in the water into the shaft-walls, thereby giving more stability to that portion of the quicksand and holding the inward pressure of the latter in equilibrium.

The sludge loosened by the percussion-drill is conveyed to the surface by means of a continuous water-flow through the hollow cylindrical drill-rod. A small gas-pipe reaches a short distance down this drill-rod, and through it compressed-air is forced, the air bubbles into the drill-rod making the water-column in it lighter than that in the shaft. As a consequence the water rises into the drill-rod from the bottom. Above the surface the water and sludge flow through a horizontal branch pipe from the drill-rod into a basin, where the sludge is allowed to settle, the separated water flowing back into the shaft. Clay is mixed in the basin with the water returning to the shaft in order to keep the water in the shaft at the required specific gravity. In an illustration the artificial water-level in the shaft is shown to be 75 feet above the water-level in the quicksand. During the sinking constant care must be exercised to keep this artificial level and the specific gravity of the water up to the predetermined standards in order to prevent the caving in of the shaft. When solid rock is reached a casing is built in the usual way by means of iron tubbing.

G. G. A.

Mine Watering-Cart.

(Engineering and Mining Journal, New York, 7 April, 1906, p. 671.)

The danger from explosions in dry coal-mines due to the presence of fine dust is now generally recognized, and various means have been devised for conveniently watering the roads and working-places. One of the latest, possessing some novel features, is the Rockwood car, which is a watering-cart acting on the same principle as a fire-engine. The car consists of a steel tank, of a capacity of 300 gallons, mounted on a travelling platform, or trolley. Inside the tank is a horizontal force-pump arranged with a system of levers and a counter-shaft whereby it can be worked by a detachable lever from the outside, or by means of an eccentric on the rear axle of the car. When the latter connection is made the pump makes one complete stroke for each revolution of the wheels. The pump has a double suction and discharge, each controlled by valves. The hand-lever is used in filling the tank from the sump or other source of water-supply. The valves are then reversed, the hand-lever detached, and the eccentric shaft connected. The water is discharged in a continuous stream from a spray-nozzle on a hose of suitable length, the pump being worked by the wheels of the car as long as the latter is kept moving. As the pump will throw a spray 30 to 40 feet, it will wash wide stalls and reach well into the gob. The nozzle being in the hands of the workman, the water can be directed where it is most needed, washing off both sides and roof, as well as wetting the floor. When necessary, as in the case of a fire or at a working-face, a stream can be thrown while the car is standing still by using the hand-lever. This car is in use in a number of collieries in the Tennessee coal-field, where it is said to be giving satisfaction.

G. G. A.

Intermediate Tamping in Blasting.

(Engineering and Mining Journal, New York, 10 February, 1906, p. 277.)

The practice of intermediate tamping in shot-holes where the rock is not of a very strong character is becoming common in the United States, and has more than once been commented on recently, and somewhat adversely, by the *Engineering and Mining Journal*. In a short article the Author reports the results of some experiments made with a view to test this system of breaking up a charge of explosive by intermediate tamping of sand, or specially made plugs of wood. The object aimed at is to distribute the charge over different points in the bore-hole. Experiments were first carried out at the surface by exploding different grades and sizes of gelatine

and gelignite cartridges in lead tubes in the open air with interposed tampings of wood, sand and water. The underground experiments were conducted in the stopes under conditions conforming as nearly as possible to those of ordinary workings. Though complete detonation occurred in every test underground, the results were considered sufficient to condemn the practice as highly dangerous. For while the experiments show that intervening sand-tamps up to 12 inches may be used without much risk of miss-fires, yet it is impossible to think otherwise than that the practice must in the long run contribute materially to miss-fires and their consequent accidents. Moreover the method has nothing to recommend it on the score of efficiency; for the same end may be gained as effectively by using an explosive of a lower grade and therefore of a larger bulk, weight for weight. But it is pointed out that while under certain conditions a distribution of the explosive agent along the bore-hole may be advantageous, yet under ordinary conditions such a distribution may bring too much of the explosive near the collar of the hole, where energy may be wasted and the shot rendered only partially effective.

G. G. A.

Rock-Drilling in Swedish Mines. K. G. Brunnberg.

(Teknisk Tidskrift, Stockholm, 1906, Chemical and Mining section, pp. 49–50.)

The use of boring-machines, which was at first confined to rising in the backs of levels, has during the past 10 years been extended to cutting plat, shaft-sinking and driving the ends. They have shown their advantages, even at a higher price per unit of depth of hole bored. In the Lomberg mining district machines weighing 40 to 50 kilograms (88 to 110 lbs.), with piston of 50 millimetres (2 inches) diameter, have bored 7·52 metres (24·67 feet) per shift of 8 hours, yielding 4·34 tons of rock per metre bored, against 3·45 tons with hand-boring (1·32 against 1·05 ton per foot), notwithstanding that the effect of the explosive was diminished from 15·90 tons per kilogram to 10·83 tons (7·21 to 4·94 tons per lb.). The cost per ton of spoil was 38·7 öre (5·2*d.*), including miners' and fitters' wages, sharpening drills, repairs and power, but nothing for redemption. Hand-boring cost only 37·6 öre (5·0*d.*) per ton, but the machine did the work of more men. In the same district the cost of driving levels of 4 square metres area has been 46·38 kronor per metre run by machine boring, including the same items as above, against about 50 kronor by hand: or say, for levels 1 fathom wide by 1 fathom high, £3 19*s.* per fathom forward by machine, against £4 5*s.* by hand. Here the chief gain is that the ends are driven more than twice as fast by machine.

Pneumatic drills are at present maintaining their superiority over electric, which only under exceptional circumstances can compete

with them. At Grängesberg the Author's experience has been that, although electric drills take less power, they are not cheaper in working, because what is gained in power is lost in diminished efficiency and in greater wear and tear. With electric drills the depth bored per core has run up to 6·80 metres (22·31 feet) in ore and 5·91 metres (19·39 feet) in country, with an average depth of 2·60 metres (8·53 feet) per hole. With pneumatic drills the corresponding figures have been 9·80 and 7·82 metres (32·15 and 25·65 feet), or roundly 2·5 metres (8·2 feet) more per core, with the advantage of better ventilation underground.

In the Rand and Ingersoll machines the piston and drill are in one piece, so that they move together. For some years trials have now been made, at Grängesberg and several other mines in Sweden, of an American water-jet machine, in which the piston is separate from the drill, and strikes it with great rapidity. Water is ejected by compressed air through the hollow drill; and as the latter always strikes on a clean surface, the effect is considerably increased, while the difficulty with the dust is obviated. At Grängesberg this machine has bored 2,940·5 metres (9,648 feet) in 290 cores, or 10·15 metres (33·30 feet) per core, where the Rand machines did no more than 7·87 metres (25·82 feet). But the difficulty is to get the steel to stand; the American drills were useless in the hard country of the Swedish mines. The Storfors Works have now succeeded in making a thoroughly good drill-steel.

The bore-holes can be drilled by machine both deeper and larger than by hand, with augmented effect. In open quarrying at Grängesberg the quantity of stone loosened per metre bored has been increased from 4·57 to 11·20 tons (1·39 to 3·41 tons per foot), and in hard compact rock to 18·70 tons (5·70 per foot), with holes averaging 2·82 metres (9·25 feet) deep and 25 millimetres (1 inch) diameter at bottom. At Kiruna, where the holes are bored twice as deep and 40 millimetres (1·6 inch) in diameter, the quantity per metre bored has averaged in 3 months 102·3 tons (31·2 tons per foot), and in some places has even gone up to 180 tons (55·0 tons per foot).

With the larger and more effective bore-holes the rock is blasted in large blocks, which have then to be drilled and blasted smaller for removal. For this purpose portable mechanical jumpers —pneumatic percussion-drills held in the hand[1] and requiring no stand—have been devised during 1905 by the Ingersoll firm and by the Atlas Company, Stockholm, both of which have been tried at Grängesberg on four different kinds of rock. The results are tabulated, showing the great superiority of the Atlas drill in depth bored per minute; and, including the time spent in clearing the spoil, the average per hour was about 80 inches with this drill against 50 inches with the other. The consumption of compressed air

[1] Compare Minutes of Proceedings Inst. C.E., 1906, vol. clxiv, p. 476.

is large; the cost for driving the Atlas runs up to about 2*d.* per foot of hole bored. The Author considers that hand-boring ought speedily to disappear from mines already equipped with compressed air. A. B.

Respirating Apparatus for Mines. G. LOUCHEUX.

(La Nature, Paris, 31 March, 1906, pp. 273-5.)

The catastrophe at Courrières has attracted much public attention to the methods of combating underground fires and to various life-saving appliances. The prevalence of after-damp is, as a rule, much more fatal to life than explosions or fires in mines, owing to the suffocating effects of the carbonic oxide gas. Some previous disasters of a similar character to that at Courrières are discussed. In the case of subterranean fires, two distinct sets of operations are needed, the one having to do with the extinction of the conflagration; the other embracing the means for saving the victims. The measures to be taken against fires in mines have been much studied, and the method of Mr. Fayol has been used with success for the past 30 years, but in the case of the miners who may be struck down, it has generally been possible only to devise means for the removal of the corpses, since those unable to reach the shafts have been invariably suffocated. The Author describes the various types of respirating apparatus, and by reference to diagrams explains that these consist mainly either of reservoirs of air or devices for the accumulation of oxygen gas and regenerating the air expelled from the lungs. Among the special forms of apparatus available, that of Guglielminetti-Dräger, which is of the reservoir type with oxygen supply, is illustrated and described. This consists of two steel flasks containing 220 litres of oxygen gas compressed into 2 litres, at a pressure therefore of 110 atmospheres, together with a regulating expansion chamber with delicate valves for the supply of the gas at suitable pressure for breathing. This outlet can be so throttled as to yield 2 litres of the expanded gas per minute, and then the supply carried is available for about 2 hours. A mask to cover the head and face and a regenerating chamber, wherein the expired air is purified by contact with potash in metal baskets, which extracts the carbonic acid gas, completes the outfit. An apparatus on somewhat similar lines by Mr. Vanginot, capable of supplying 1,100 litres of air at normal pressure, in which atmospheric air is stored under pressure, is also described. The possible yield of air for breathing is at the rate of 120 litres per minute, a quantity in excess of what is actually needed.

G. R. R.

Splitting Granite by Compressed Air.

(Engineering and Mining Journal, New York, 19 May, 1906, p. 948.)

A remarkable method of quarrying by compressed air is in use at the North Carolina Granite Corporation Works at Mt. Airy, N.C. The property covers a gently sloping hillside, consisting of a solid, homogeneous mass of moderately hard granite, showing no ledges or bed-planes. The stone splits readily in a straight line in almost any direction. Advantage is taken of this property to utilize the pressure from compressed air to make artificial ledges to work to. By this means the rock is removed in layers or laminations, after the manner in which an onion is peeled. The mode of procedure is as follows:—in the centre of the area over which the rock is to be removed, a 2-inch or 3-inch shot-hole is drilled to a depth of 6 to 8 feet, according to the greatest thickness of stone required. The bottom of this hole is then "pocketed," by exploding half a cartridge of dynamite in it. A handful of black powder exploded in this pocket is sufficient to start a horizontal crack or cleavage plane across its greater diameter. Successive charges, increasing in size, are exploded in the cavity to extend the cleavage, the drill-hole being plugged for each shot. When the cleavage has been extended in this way to a radius of 75 or 100 feet, a pipe is cemented into the hole and connected, through a glove valve, to the air-pipe line from a compressor. Air at 70 or 80 lbs. pressure is gradually admitted, and the cleavage is rapidly extended till it comes out on the hillside in a thin edge. A sheet of several acres in extent may be raised in this manner, affording a bed-plane that is approximately horizontal, from which the quarrymen can break out blocks of any required thickness. The Author describes a case in which the time occupied in starting the cleavage and extending it to a distance of a 100-foot radius was between 2 and 3 weeks; while the subsequent splitting of the much larger area up to 225-foot radius was done by compressed air in half-an-hour. Water under pressure was tried, but compressed air was found to be cheaper and more convenient.

G. G. A.

Electric Smelting and Refining of Iron. A. Grönwall.

(Teknisk Tidskrift, Stockholm, 1906, Chemical and Mining section, p. 50.)

The process devised by the Author comprises two stages:—the reduction of the iron ore, and the melting and refining of the metal. The reduction is effected in a blast-furnace somewhat smaller than

usual, by means of carbonic oxide gas supplied from what looks like an ordinary hot-blast stove. The blast-furnace is blown in as usual with a charge of ore and charcoal. The gas there formed is drawn off by an exhausting or blowing fan into the stove, where it is heated electrically to 1,000° or 1,200°. Passing next through a layer of charcoal, it becomes rich in carbonic oxide; and after being further heated electrically to the highest temperature the fire-brick will stand, it is delivered into the furnace at about the level of the tuyeres. After so starting, it gets to circulate continuously through the furnace and stove; less charcoal is charged into the furnace, or none at all; the blast is shut off, and the nitrogen it had brought in becomes more and more diluted, since the oxygen liberated from the ore, combining with the carbon in the stove to form carbonic acid or carbonic oxide, increases the quantity of gas.

For melting and refining the metal from the ore, an electric oven is so combined with the furnace as to be partly outside and partly within the furnace-hearth. The plan is so contrived as to dispense with the need of any electrodes in the furnace. The refining is done in that portion of the electric oven which is outside the furnace; it can be effected in the same way as in other methods. The use of charcoal can be replaced by electricity to the extent desired. There are no losses through escape of gases mixed with air. The refining begins at once on the melting of the metal. The electric current can be either direct or alternating, single- or three-phase, of 20 to 50 volts, and with a frequency of 25 to 50 cycles per second. The process is about to be tried in an experimental set in course of erection (January, 1906) at the Ludvika Iron Works.

A. B.

Reduction of C... Ores by ... ctric Furnace. G. DARY.

... n, P ... xxi, pp. 276–8.)

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is drawn off from the surface of the bath, while the matte is drawn off at the bottom. Analysis of the products obtained by this process has shown that the matte contained 47·9 per cent. of copper, while the slag contained copper to the extent of only 1 per cent. Further treatment of the matte is performed by the usual processes. This method has various advantages over that in which the coal or coke furnace is used, and is much more economical in places where coal is dear and electrical energy cheap. That is to say, the electro-metallurgical process can only be adopted in districts where coal is dear, and where there is a plentiful supply of water-power to justify the erection of hydro-electric generating-stations.

W. C. H.

Control of Submarines by Wireless Telegraphy.

J. A. MONTPELLIER.

(L'Électricien, Paris, 1906, vol. xxxi, pp. 289–92.)

The Author describes a method devised by a French Engineer, Mr. Lalande, for controlling a submarine from a distance by wireless telegraphy so that it may be propelled and steered, and made to launch a torpedo at the will of the distant operator. The submarine has a number of electric circuits—one for the propeller-motor to drive it ahead or astern, one for steering, one for the torpedo-apparatus, and so on—and in Mr. Lalande's system the arrangement is such that any particular circuit is completed when a rotating pointer reaches a particular point on a circular disk. The movement of this pointer is controlled by the closing of the coherer-circuit, and the distance it travels round the scale depends on the number of sparks sent out at the sending station. The operator there has a similar disk and pivoted arm, and the number of sparks emitted is proportional to the displacement of the arm round the disk. Tests were made with a model submarine in March off the French coast, the operator being on land, and the cruiser *St. Louis* took part in the trials. The results are said to have been wholly satisfactory, the boat performing each operation that was demanded of it. The submarine is constructed to remain at about 3 yards beneath the surface, but masts with the antennas project above the water.

W. C. H.

Submarine Sweeps for Locating Obstructions in Navigable Waters.

F. C. SHENEHON, M. Am. Soc. C.E.

(Engineering News, New York, 26 April, 1906, pp. 462–4.)

It is usual in modern practice to examine any submarine excavation for a ship-canal or harbour before acceptance from the contractors not only by soundings, but also by a sweep, to make certain that no isolated points project above the specified level. In its best-known form a sweep is a bar or bars of iron suspended from a raft or scow or series of pontoons at the given depth below the water-surface. This moves over the area under examination so that the bars pass over every foot of it, and some tell-tale device indicates if the bars come in contact with any obstacle. In preparing the pontoons for work in Lake Erie in the spring of 1905 the five sections were equipped with a sweep of galvanized wire 0·1 inch in diameter instead of iron bars. The wire was continuous from the stock reel over an over-hanging sheave, down through a 300-lb. terminal weight at the depth of the sweep stem, then forming 200 feet of the horizontal sweep in 40-foot spans, threaded through intermediate 100-lb. weights and through a terminal weight of 300 lbs. at the other end, thence up to the deck again, where it was fastened by a hook to a 200-lb. spring balance. A normal tension of about 60 lbs. was applied by straining on the stock reel. At the ends of the sweep the tension tended to draw the terminal weights towards each other, hence their greater weight. The vertical sag of the wire in the 40-foot spans was less than ½ inch. The total submerged weight was 1,000 lbs. and its total resistance 300 lbs. at 5 miles per hour, the angle of back slant at this speed being 30°. The spring-balance gave unmistakable indications of the presence of an obstacle.

In 1902 the writer designed a long wire sweep, which has been used to a length of 3,000 feet. It consists of a series of 100-foot sections of 0·1-inch galvanized iron wire—or ⅛-inch diameter galvanized signal-cord in sections of 100 feet—linked together with light iron rings or swivels and stretched taut at the given depth below the surface under a tension of about 70 lbs. At each link is a detachable 10-lb. cast-iron ball, and from each ball a suspending wire passes up to a spherical buoy, which supports the sweep wire. At the ends of the sweep the wire is fastened to 300-lb. cast-iron balls, from which ⅜-inch cables lead to the large towing buoys. In operating the sweep two launches, one attached to each towing buoy, move the sweep over the assigned course. The launches head on courses diverging from each other and from the line of travel at an angle which keeps the sweep taut and at the same time advances it along the course. A sweep of this nature 1,200 feet long will cover a belt of over 1,000 feet at a speed of upwards of 1 mile per hour, and has a capacity in unobstructed areas of 2 square miles per working-day. When an obstruction is met by the sweep wire the fair curve assumed by the intermediate buoys is distorted.

The long sweep wire does not obstruct navigation in the path in which it is operating, as vessels may pass in the 100-foot spaces between the intermediate buoys.

A. W. B.

New Waterworks and Reinforced-Concrete Conduit of Mexico City.

J. D. SCHUYLER, M. Am. Soc. C.E.

(Engineering News, New York, 19 April, 1906, pp. 435–8.)

A new system of water-supply is under construction for the City of Mexico for a population of 400,000. The supply is being brought to the city in a conduit of reinforced concrete a distance of about 17 miles from large springs near the village of Xochimilco. The springs issue, over a distance of several miles, from the foot of the high mountains lying to the south-east of the city, and are practically constant in volume. The conduit is 6 feet 3 inches high, and has a fall of 3 feet in 10,000. It is located so as to obtain a cover of about 3 feet. The water is lifted into the conduit at the upper end by suitable pumps, and its carrying-capacity of 40,500,000 gallons per 24 hours can be increased to over 50,000,000 gallons per 24 hours by raising the head at the upper end so as to increase the slope. The width of the right of way provided for building the conduit is 82 feet. A narrow-gauge railway was first built for the entire length, and a stone-crushing plant was erected about midway. An electric power-transmission line was laid alongside the trench to furnish current to motors operating pumps, rock-crushers, concrete-mixers, etc. The rock used for concrete is hard basalt, which crushes readily, and produces all the sand required. A continuous cylinder of expanded metal strengthens the concrete conduit to resist the water-pressure.

A. W. B.

Radio-activity of Sources of Drinking Water. F. DIENERT.

(Comptes Rendus de l'Académie des Sciences, 1906, vol. cxlii, pp. 883–5.)

The Author has tested the radio-activity of the different sources from which water is supplied to Paris, and in this Paper he gives the results of these tests. Apart from this comparison, he arrives at the general conclusions that there is no apparent relationship between the electric conductivity of the water and its radio-activity, and that for the sources examined those appear to be most radio-active of which the areas of supply are very rich in white clay. No radium was found in any of these waters.

W. C. H.

New Paris Sand Filters. Le Couppey de la Forest.

(La Nature, Paris, 21 July, 1906, pp. 120–3.)

The Prefect of the Seine, Mr. de Selves, inaugurated the new filters for the Paris Suburban Water Company on the 27th May, 1906. These filters will serve an outlying district with a population of 160,000, and as these works will furnish 7,700,000 gallons daily, the supply will be 48·1 gallons per head. Until now the district served has been supplied with Seine water unfiltered. The general arrangement of the works is shown by a block plan, and photographs are given to explain the working of the various beds. Before the water passes on to the beds it is clarified by simple deposition and straining in a set of four small tanks, each subdivided into four parts for cleaning out and repairs. Here the water is cleared of its grosser impurities by passing through coarse gravel. It then flows on to the first filters, which are of large-grained sand, through which it travels about seven times as fast as through the final beds: the speed of filtration slowing down from the first to the last filters, while the beds traversed gradually increase in thickness. Between the various filters the water falls in cascades for the sake of the aeration. A siphon regulator on the Didelon system, of which illustrations are given, is here employed for the first time. The various rates of filtration are set forth in a table. It is stated that since filtered water was supplied to this district, in lieu of raw river-water, the mortality from typhoid fever has sunk, as compared with the corresponding period of last year, from 180 per 100,000 to 43 per 100,000. This is below the totals for Paris during the same period, where the mortality was at the rate of 67 per 100,000.

G. R. R.

Surface-Water Filtration in Queensland. Hardolph Wasteneys.

(Paper read before the Royal Society of Queensland, August, 1905.)

The reservoir in question, the Enoggora reservoir, is situated near Brisbane. The watershed is 8,295 acres, free of human habitation but open to cattle. The capacity of the reservoir is 1,000 million gallons. The surface area when full is 186 acres, about one-third of which is shallows less than 13 feet deep. The maximum depth is 55 feet. The average rainfall for the last 5 years was 33·93 inches. The creeks which flow into the reservoir are practically dry, except during and shortly after rain. There remain in the bed of the creeks, however, water-holes swarming with growths of *Spirogyra*, etc., which are washed into the reservoir when the creek again flows.

The water in the reservoir is stagnant from July to May; during May and June there is vertical circulation. During the stagnant period the colour of the water increases with the depth. Below

20 feet there is no dissolved oxygen and little life. Sulphuretted hydrogen gives the bottom layers an offensive smell. Towards the end of May vertical circulation sets in. The water with the colouring matter from below comes up and mixes with the other water, making the water throughout all depths practically similar in composition and colour. On the 19th May, 1905, before the vertical circulation set in, the surface water gave 1·9 units of red and 6·5 of yellow in Lovibond's tintometer, the bottom-water figures being 42·0 of red and 32·0 of yellow. On the 5th June, 1905, after the cold weather had started vertical circulation, the corresponding figures for the surface water were then 3·0 of red and 10·0 of yellow, and for the bottom 2·7 of red and 8·0 of yellow. The proportion of iron increases directly with the colour, which is therefore probably due mainly to iron.

The bacteria contents average about 400 per cubic centimetre grown on neutral agar at blood heat. Micro-organisms:—The diatom *Synedra ulna* and the alga *Clathrocystis aeruginosa* are always plentiful after rain. *Clathrocystis aeruginosa* is the predominating organism and occasionally forms a bright green scum.

On a neighbouring reservoir it gave the water the consistency of thin mud, and the stench was unbearable. *Spirogyra* grows abundantly during the summer. *Bryozoa plumatella* grows thickly in the delivery mains, and is growing and decaying all the year. It sometimes extends inwards for 5 inches, the 2 inches next the main forming a thick mat. Freshwater sponge and hydra grow with the *plumatella*. The smell from the decaying *plumatella* and sponge often renders the water most offensive. The smell of the water varies with the seasons, and has been described at various times as vegetable, salt-marshy, grassy and fishy.

Tables of analyses are given showing that the free ammonia is low. The albuminoid ammonia varies from 0·260 to 0·367 per million.

The colour varies from 52 to 20 parts per million on the platinum scale. Chlorine is constant at 2·4 grains per gallon. Hardness about 3 degrees. Nitrates and nitrites are absent, and the total solids are about 112 per million.

The following sizes of sand were used in the experiments:—

	Effective Size. Millimetres.	Uniformity Coefficient
Morry filter (sand and gravel)	0·36	3·55
Plain sand filter	0·335	2·83
Sand and ashes	0·28	2·07
Combination of Morry and plain sand filters	0·28	1·74
Intermittent plain sand filter	0·27	2·50

Details of the various filters, and Tables showing aquatic plants, micro-organisms, rainfall, temperature, bacteriological contents, chemical and physical analyses, and comparisons of analyses of the various filter-effluents, are given in the Paper. It is remarkable that plain sand filtration gave reductions in organic matter almost equal to those obtained by any other method.

The following Table summarizes the results of various methods of filtration :—

AVERAGE PERCENTAGE REDUCTION IN ORGANIC MATTER, COLOUR AND BACTERIA, EFFECTED BY THE VARIOUS TYPES OF FILTERS USED IN CONNECTION WITH THE EXPERIMENTAL PURIFICATION OF THE LAGOON WATER.

Type of Filter.	Period for which Average Reduction is Calculated.	Rate of Filtration (Million Gallons per Acre per 24 hours).	Average and Reduction.					
			Albuminoid Ammonia.	Oxygen Consumed.		Colour. Lovibond Tintometer.		Bacteria (grown on Neutral Agar (medium).
				15 Minutes.	4 Hours.	Red.	Yellow.	
	Days.							
Morry Filter (sand and gravel)	139	2·1	54·0	40	39	93	67	91·8
Plain Sand Filter . . .	183	2·0	53·0	33	36	93	66	98·5
Sand Ashes	214	2·1	53·5	40	39	97	70	92·6
Machine Filter (Coagulants used)	80	104·0	56·0	57	41	..	..	..
Combination of Morry Filter and Plain Sand Filter .	17	2·2	59·0	35	42	100	68	97·3
Intermittent Plain Sand Filter	62	2·1	58·0	43	43	99	66	74·2

Dr. Moore's method of destroying algal growths in reservoirs by the addition of copper sulphate to the water was also tried on an experimental scale with considerable success. The most obnoxious forms were found to be effectively removed by the addition of 1 part of copper sulphate ($CuSO_4$, $5H_2O$) to 8 to 10 million parts of the water, and it was suggested that a still smaller quantity would be necessary if treating the reservoir itself. No copper could be detected in the water 3 days after the addition. It was stated, however, that in spite of the success of the treatment it could not be said to remove the necessity for filtration.

C. W. S.

Sterilization of Water by Ozone. E. BONJEAN.

(La Nature, Paris, 23 June, 1906, pp. 55–8.)

Apparatus capable of dealing with 33,000 to 44,000 gallons of water hourly by the ozone process of de Frise has been installed at the Paris waterworks at Saint-Maur, and the results of certain

experiments conducted by Mr. Ogier and the Author and by Messrs. Miquel and Lévy for the Paris authorities are here described. By means of illustrations and diagrams an account is given of the works and plant, which comprise a 45-HP. engine with centrifugal pumps capable of lifting 32,000 gallons per hour to a height of 49·2 feet, an alternating-current dynamo with 100 periods, a transformer calculated to increase the tension to 40,000 volts, together with separators, dryers, large and small ozonizers, sterilizing-chambers and various pumps. The water submitted to treatment was either the natural water of the River Marne or the same after passing through the ordinary sand-filters. The ozone is generated from the atmosphere by silent electrical discharge, and the number of electrodes can be varied in accordance with the volume required, as many as 900 being used in certain of the experiments. The sterilizer is the vessel in which the water is brought into contact with the oxygen. It is a metal tower or cylinder with a dome at the summit, the water and the air impregnated with ozone pass upwards together for the whole distance of 26 feet, in 5 to 15 minutes, and have to traverse in their ascent a series of celluloid screens, placed horizontally across the tower and perforated with a vast number of minute holes about 0·027 inch in diameter. By this means the ozone is caused to act on the water, which action is facilitated by the passage through the numerous perforated screens. The amount of ozone contained in the air varied between 0·88 gramme and 1·6 gramme per cubic metre. The water as a rule was sterilized by the use of about 1 gramme of ozone to the cubic metre of water. It is stated that to generate the ozone and to work the plant represents an hourly expenditure of 3·5 kilowatts, or say, 4·8 HP. per 100 cubic metres of water (22,000 gallons). Very satisfactory results were obtained by Messrs. Miquel and Lévy during a set of tests from January to March and again in December, 1905.

G. R. R.

Ozone Treatment of Water. Prof. PROSKAUER.

(Gesundheits-Ingenieur, Munich, 9 June, 1906, pp. 403–6.)

In consequence of the opinion expressed by Mr. Halbertsma, Director of the Wiesbaden Waterworks, adverse to the success of the ozone process as carried on at the works in question, Dr. Karl Schreiber has published an article on the subject, refuting the contentions of Mr. Halbertsma and giving the results obtained by means of the ozone process at the Paderborn Ozone Works, where this system has been in continuous use for 3 years. It is shown by the observations of the water that the germs present in the untreated water were reduced to a minimum by exposure to ozone, and that during regular working there was always an excess of ozone present in the effluent after treatment. The success of the

process at Paderborn, as tested by the methods proposed by the Author and Dr. Schrieber, is stated to have been demonstrated, and certain matters in connection with the mode of conducting the operations at Paderborn are discussed. The Author maintains that Mr. Halbertsma seems to possess a personal antipathy to the use of ozone with drinking-water, and quotes the adverse remarks uttered by him at the meeting at Cassel in 1899. Mr. Halbertsma moreover has stated that the Author had said that pathogenic germs were among the least resistant of bacteria, and that where the bacteria were destroyed the pathogenic germs would be the first to be exterminated. The Author denies that he has ever published this opinion, and he states with respect to the use of ozone that this method of treatment furnishes a means of procuring drinking-water of unobjectionable quality, and that, according to his own observations, the employment of ozone is a very valuable measure for the sterilization of water. He refers to the proceedings of the Congress of Applied Chemistry at Berlin in 1903, when he testified accordingly.

G. R. R.

Drain-Pipes: Cement v. *Clay.*

(Teknisk Ugeblad, Christiania, 1906, pp. 160–1, and 172–4, and 197–200.)

In the Norwegian Parliament recently the Chief of the Water and Sewage Department in Christiania is reported to have said that investigations and tests had shown cement pipes to be good in all respects, and on a level with those made of clay: the cement pipes stood far heavier loads passing over them, and the fear of their being attacked by acids had now been dispelled. These statements, and also the alleged impervious nature of cement pipes, are controverted by Mr. C. Salicath, engineer, Christiania, who objects that, while the bodies of the pipes were tested for crushing, no such tests were made on their sockets, which are their weakest part and are too slender. In his own experience, more than 90 per cent. of the breakages of pipes are due to damaged sockets, in consequence of the pipes having been so badly laid that they rest on their sockets. Porosity was tested by standing the pipes upright with the bottom end closed, filling them with clean water, and noting how much it sank in 36 days. But this is no criterion for sewage; and any moisture oozing through the walls of the drain-pipes would do no harm, having been thoroughly filtered by the percolation. When investigating the manufacture of cement in Germany, he had never heard of porosity tests; but when pipes which had lain in the ground for a length of time were taken up and examined, it was found that those made of cement had been attacked by grease, acids and warm water, where clay pipes had remained sound. Hence it had been stipulated that waste water from factories must not contain more than 2 per cent. acid, and must not be hotter than 39° C. = 102° F.; and similar stipulations had been introduced in Norway.

In a rejoinder from the Christiania Water and Sewage Department, it is recognized that cement is attacked by various acids in greater or less degrees; and it has accordingly been laid down that waste water must not be discharged into the sewers, if it contains more than 0·1 per cent. of acid, and is hotter than 35° C. = 95° F. Acid so greatly diluted is believed, according to information from abroad, to have no injurious effect on cement. Moreover the slimy film, or so-called sewer-skin, which becomes deposited as a lining in all sewers, forms an important protection. The crushing tests are found to be the most important of all, serving for a direct comparison between the strengths of cement and clay pipes; in exposed places in the streets the latter are particularly apt to be crushed, because they crack lengthwise. In rolling the ground after the trench has been filled in, the pressure to which the pipes are exposed is by no means light. Porosity tests have been carried out mainly for the sake of comparison with those made at the testing works in Stockholm and likewise in Malmø. They are also of importance, inasmuch as the quantity of water exuding through the walls is at any rate to a certain extent a measure of the density of the material: and the denser the material, the better do the pipes withstand acids.

As manager of the Stavanger Cement Factory, Mr. Sven Oftedal points out that these works were not started without previous minute examination of the conditions attending the industry in Denmark, Sweden and Germany. After recording his observations at considerable length, he summarizes as follows the view prevailing abroad on the question of cement *contrà* clay. Owing to the nature of the material and its inability to withstand the action of damp earth, clay pipes ought to be used as little as possible for sewers, inasmuch as, irrespective of the sewage-water, they rot all over from lying in the ground. Cement pipes ought to be used for all main sewers, and for most branch drains, as sewage-water has been found to have no injurious action on cement pipes, and they do not rot in damp ground. But they should not be used in special situations, such as drains from chemical works and laundries, where the waste water may be liable to be too acid or too hot. Under such special circumstances, so far as concerns chemical action, clay pipes can be used, but still with the aim of ultimately getting them superseded by a more suitable material. Even under conditions theoretically undesirable for cement pipes, the choice may be made in their favour, because the lining film, or sewer-skin, forming the surface along which the sewage-stream glides, protects them from the action of acids. In Stettin, where clay pipes are used, they are manufactured at particular works under special precautions, and are glazed like slag throughout their entire substance. Elsewhere a quantity of second-class clay pipes are made, which among other defects are often oval, and therefore leaky at their sockets; whereas the cement pipes are of truly circular section. The experience of Sweden and Germany is that of countries which themselves produce pipes both of cement and of clay; if they are more and more going over to cement, it must be solely because cement pipes prove more successful and more suitable. For Norway,

which has to import all her clay pipes, it is all the more a matter of national economy to use home-made cement pipes. Clay pipes are everywhere giving place to cement; and in this instance it is happily a foreign manufacture which must here make way for a Norwegian product. Every hint for improving the Norwegian manufacture is therefore welcome.

A. B.

Sewerage of Centerville, Iowa. ARTHUR J. COX.

(Engineering Record, New York, 24 March, 1906, pp. 404–7.)

This work was designed to meet rather difficult topographical conditions. The town is built on a ridge, buttressed by lateral ridges enclosing deep ravines, and contains two unequal areas draining in opposite directions, but ultimately to the same river. As the fall each way is 120 feet in less than a mile, one main outfall sewer was out of the question. The town, which is 2 miles long and 1¼ mile wide, is divided into eight drainage-areas, four of which only have been dealt with at present, comprising over 19 miles of sewers and two septic tanks.

The complications arising from the steep natural grading, and the methods by which they were met are clearly set forth. All of the excavating in one area was done by hand labour, while that in two of the other areas was done both by hand and by a Chicago sewer-trench excavator, made by the Municipal Engineering and Contracting Company. Under favourable conditions, the latter dug ditches 32 inches wide, and 9 to 14 feet deep at about 1 lineal foot per minute. Some of the best records were 350 to 400 feet per day, the maximum being 275 feet in 145 minutes with an 11-foot trench. The hardness of the earth makes little difference in speed, pebbles and stones being easily taken out if not solidly cemented together. The septic tanks are described, and the article includes three most useful tables containing over 2,000 figures, giving the cost of excavation and pipelaying with quantities, hours, rates of wages, and under hand- and machine-work, with the conditions governing each: data most valuable in estimating similar work elsewhere.

C. O. B.

Lighting of Victoria Station.

(The Engineer, London, 15 June, 1906, p. 601.)

The new Victoria Station is lighted by high-pressure gas. When the station is completed there will be nearly 400 lamps varying between 175 and 1,000 candle-power, and giving a total light of 140,000 candle-power. Gas is supplied at a pressure of 50 inches from

two Sale-Onslow compressors, each capable of delivering 5,500 cubic feet per hour, driven by gas-engines, the plant being duplicated throughout, and the shafting so arranged that either engine can drive either or both compressors. Two smaller compressors, driven from the same shafting, are provided for use when only a small number of lights are required. The compressors are fed by a 6-inch main through two 500-light dry meters. The platforms, except those on either side the carriage-drive, which are lighted with 500 candle-power lamps, are lighted by Sugg's lamps of 350 candle-power, one lamp being placed between each pair of columns carrying the roof, the distance between the lamps being about 50 feet, and their height above the platform-level about 12 feet. The lamps lighting each platform are controlled by two taps placed at the end of the section, each tap controlling alternate lamps. A special cup-and-ball joint is used for connecting the down rod of each lamp to one of the two main supplies, and to the by-pass service, each lamp being connected to the down rod supplying it by a similar joint, so that the effect of vibration on the mantles is reduced to a minimum. Each section of the by-pass is fitted with a governor to regulate the pressure to 2 inches; the by-passes are completely extinguished by the act of lighting the lamps. The station-yard beyond the platform is lighted with four "Belgravia" lamps, each 1,000 candle-power, carried by two weldless steel columns 25 feet, and two 30 feet high. These lamps are worked by control taps placed at the base of the columns.

A. W. B.

Laying a Submerged Gas-Main.

(Engineering Record, New York, 21 April, 1906, pp. 5??-3.)

The unusual operation of laying an 8-inch gas-main across the Fox River at Oshkosch, Wisconsin, is described. The river is 525 feet wide, 35 feet deep at centre, and carries 60,000 to 100,000 cubic feet per minute. The main is made of standard cast-iron hub-and-spigot 12-foot water-pipes, with lead joints, every third joint being made a flexible one to facilitate the laying and to permit the main to adjust itself to the bed of the river. The latter is partly of rock and partly of gravel overlaid with 18 inches of very soft silt. A trench was excavated through the silt by a hydraulic jet under 140 lbs. per square inch pressure, handled by a diver with an ordinary fire-hose nozzle with ½-inch opening. By means of a scow and a stiff leg derrick, each 36-foot rigid length was lowered horizontally, the flexible joints, which are of the Falcon ball-and-socket type with bolted flange-connections and lead gasket between, being made by the diver, armed with a pneumatic hammer fitted with a caulking tool. The joints above water were made with the same tool, the air-power for both being supplied by a Blake air-compressor.

Gate-valves are provided on each shore, in order that the pipe may be cut out of service. A 12-foot length of 16-inch pipe blanked at

one end, and attached by a flexible joint to the 8-inch main, was placed transversely at the lowest point of the latter to receive what condensation might occur. A 1-inch heavy pipe of lead, which was adopted to avoid the corroding action of the water on wrought iron connected this condensation collector with a well on shore, from which the leakage and condensation, estimated at a maximum of 4 gallons per day, can be pumped.

C. O. B.

Mariendorf Vertical Retorts.

(Journal für Gasbeleuchtung, Munich, 24 March, 1906, pp. 250–60.)

Mr. Körting has submitted a report as to the working of vertical retorts at the Experimental Works at Mariendorf. The daily production of gas is 210,000 cubic feet. The settings are similar to those at Dessau,[1] but adapted to retorts 5 metres (about 16½ feet) long.

The heats maintained in the settings were good and equally distributed. The coke produced was of remarkably good quality, and gave such satisfaction to purchasers that it is to be hoped that coke thus produced will fetch a higher price than the ordinary material.

As regards the production of tar, 100 lbs. of coal (mostly English) yield 4·2 lbs. of tar, the quality of which is shown from the comparative results obtained:—

Temperature of Distillation.	Tar from Vertical Retorts.		Tar from Inclined Retorts.	
Degrees.	Oil. Per cent.	Water. Per cent.	Oil. Per cent.	Water. Per cent.
0 — 100	8·9	5·7	1·0	0·85
100 — 170	1·2	..	1·6	1·85
170 — 230	13·5	..	7·5	..
230 — 270	7·3	..	10·27	..
Above 270	29·3	..	18·80	..
Residue	34·1	..	58·13	..

The yield of ammonia in December was	7·35 lbs.
That of the Mariendorf inclined retorts on an average during 1905 was	4·93 lbs.
The vertical retorts thus produced an excess of . . .	2·42 lbs., or, say 50 per cent.

At the present price of nitrogen this increase represents at least 0·85*d*. per 1,000 cubic feet of gas, or £3,125 for each Mariendorf retort-house per year.

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[1] See Minutes of Proceedings Inst. C.E., vol. clxiii, p. 429.

The yield of gas can be seen from the following table:—

Kind of Coal.	Weight of Charge per Retort.	Yield of Gas per ton of coal Carbonized.	Calorific Value of the Gas per Cubic Foot.	Period of Distillation.
	Cwt. Qrs. Lbs.	Cubic Feet.	B.Th.U.	Hours.
Ruhr	12 3 21	11,358	588	12
Silesian . . .	11 0 13	11,513	601	10·3
English No. 1 .	12 2 5	11,803	610	11·16
,, No. 2 .	12 1 11	10,439	621	11·4

The low specific gravity of Silesian coal accounts for the abnormal weight of charge and period of distillation. English coal No. 2 is poor as regards yield of gas, but the gas gives high calorific results.

For comparative purposes the average calorific values of gas produced by different settings, were taken during two months, and averaged:—

Vertical Retorts . .	604 B.Th.U. per cubic foot	
Inclined ,, . .	584 ,,	,,
Horizontal ,, . .	570 ,,	,,

With horizontal retorts a large space must be left free to facilitate the introduction of discharging apparatus; the gas leaves the retort slowly with a consequent reduction in calorific value. Inclined retorts may be charged much more fully, and the yield of gas per unit of time is greater. The gas leaves the vertical retorts more quickly still, and thus the greatest calorific value is obtained.

In conclusion, an analysis of the gas obtained from vertical retorts is given:—

Gross calorific value . . 610 B.Th.U. per cubic foot.

CO_2	1·6	per cent.
O	0·4	,,
C_nH_m	3·8	,,
CO	6·7	,,
H	57·5	,,
CH_4	26·8	,,
N_2	3·2	,,

E. V. B.

Regulation of Tension in Alternating-Current Networks.

J. BÜCHI.

(L'Éclairage Électrique, Paris, 1906, vol. xlvii, pp. 291–5.)

The Author describes a new system of regulating the tension at different points on a network using alternating currents so as to keep the pressure as nearly constant as possible. The simplest form of apparatus is that designed for use on single-phase circuits, and that alone need be here described. It consists primarily of an auto-

ransformer, of which the primary coil is connected across the mains, rhile the connection from one main branches also to one of two uxiliary feeders. The secondary coils of the transformers, which are he regulating coils, are in series with each other and with one of the nains, and from the junctions of the coils with the main and with ach other wires are brought each to one terminal of separate interupters forming a series. The other terminals of these interrupters re connected to the other auxiliary feeder through two bars which an be put in short-circuit by another interrupter and are also shortircuited through a choking-coil. The object of using two bars nstead of only one is to prevent short-circuit of a transformer-coil vhen two interrupters are closed at the same time. The connections re such that the interrupters in succession are joined to alternate ars. If the first interrupter is alone closed, all the coils are inserted n series with the line, and the tension on the auxiliary feeders is aised above that on the mains. This tension is reduced if the second nterrupter is closed, as one coil is then cut out, and still more if the hird interrupter is closed, as two coils are then cut out, and so on. In operation the second interrupter may be closed while the first is still closed without causing a short-circuit, and the first may then be opened without interrupting the current. The arrangement is identical, but of course more complex, for use with two-phase and three-phase circuits. The Author gives diagrams of the apparatus and connections, which show clearly its operation. The apparatus has been in use for 6 months with satisfactory results at Romont in Switzerland. The interrupters are immersed in oil and operated by a shaft having cams, one for each interrupter, and the design is such that it is impossible to make a false connection which would give rise to an accident.

W. C. H.

Single-Phase Equipment for the Central Illinois Construction Company.

(Engineering Record, New York, 31 March, 1906, p. 436.)

Owing to the extended territory which this Company eventually plans to cover, and after investigation, they propose to adopt singlephase alternating current for an additional 80 miles of track under construction, and for future extensions.

The present equipment is direct current for heavy suburban type cars, with four General Electric 75-HP. motors; but the cars intended for the new extensions will be heavier. The investigation as regards the latter was into the merits of direct-current rotary-converter, and alternating-direct motor systems, and the Company have adopted alternating-current single-phase motors. These comprise for passenger-service, ten 75-HP. alternating-current compensated motorcar equipments, together with necessary sub-stations, overhead and generating equipment. Each car will have four 75-HP. motors

with the Sprague-General Electric system of multiple control adapted for use on alternating-current circuits, and so arranged as to permit tap control when running on alternating current, and series-parallel resistance control when on direct current. The trolley will be of the pantograph type with rolling contact, raised and lowered by compressed air.

For hauling goods, locomotives of the eight-wheeled type equipped with four General Electric 125-HP. compensating alternating-current motors will be used. Each of these will weigh 50 tons with a draw bar pull of 20,000 lbs., and will haul its train at 20 miles per hour with current supply at 3,300 volts and 25 cycles per second. They are adapted like the cars, for operation on both direct and alternating currents. The brake-equipment on each class of vehicle is also described.

The increase to power-station rendered necessary for the extended work consists of a 2,000-kilowatt Curtis steam-turbine, furnishing current at 25 cycles per second. The overhead and sub-station work are included in a general account of the installation, which is supplied by the General Electric Company.

C. O. B.

Synchronous Converters v. *Motor-Generators.* C. P. Fowler.

(Electrical World, New York, 1906, vol. xlvii, pp. 1078–80.)

In connecting alternating-current and direct-current networks the link may be supplied by a synchronous converter or by a motor-generator, and this Paper is devoted to a comparison of these two types of machinery in respect of efficiency, floor-space and cost, regulation and voltage-control, overload-capacity, starting, power-factor, frequency and reversibility. Only that type of motor-generator is considered in which a synchronous motor is used, and the motor-armature is assumed to be wound for the direct application of the working voltage of the system, 6,600 volts. The results of the Author's comparison are as follows. In efficiency, including in the one case losses in transformers and in the converter, and in the other case losses in motor and generator, the advantage is with the converter at full load and becomes more marked at lighter loads. The cost per ton is less for the converter than for the motor-generator, but in floor-space the latter has the advantage, unless the transformers for the converter be mounted on a gallery, when the position of affairs is reversed. In regulation and control the motor-generator has an advantage in point of simplicity, as the direct voltage bears no fixed ratio to the alternating voltage, and the former may therefore be gradually varied over a wide range by shunt field control of the direct-current generator, a simpler method of control than that usually adopted with converters. In overload-capacity the converter has the advantage. For a given amount of copper and iron the converter is superior in output to the motor-generator, and further, the load which may be carried by the

converter is not dependent on the mechanical torque, as is the case with the motor-generator. The two types of apparatus are about equal as regards starting characteristics, and they both exhibit a tendency to hunting, but whereas anti-hunting devices have been successfully applied to converters, the employment of such expedients becomes prohibitive with synchronous motors wound for direct reception of high voltages, owing to the excessive eddy-current losses in these damping devices. The converter has an advantage over the motor-generator in stability of power-factor, as there is no appreciable torque on the shaft and the power-factor is practically independent of the load on the generator. In the motor-generator the state of affairs is different on account of the mechanical transference of power from motor to generator. As regards frequency, since the motor-generator consists of two electrically independent units, each may be designed for its intended purpose, and the synchronous motor may be designed for operation without difficulty on circuits of 25 and 60 cycles per second, frequencies now largely in use. The conditions are different in the converter, but at 25 cycles the converter shows an excellent performance. At the higher frequency of 60, however, its behaviour is faulty. As regards reversibility, where direct current is converted into alternating current, the motor-generator speed is no more stable than that of the converter, and with the latter a separate direct-connected exciter may have to be used to maintain the speed at its normal value.

Each type of apparatus has a field of its own where it can be most advantageously employed. All things considered, the converter is decidedly advantageous for use in an urban system supplying power to lamps and motors from a large central station at a moderate frequency, while the motor-generator shows its superiority when operating on a system having a relatively poor regulation, as in the case of lighting-circuits from a long transmission-line, and also for furnishing a desirable method of obtaining a direct current for railway service from 60-cycle systems.

W. C. H.

Synchronizers and Power-Factor Indicators. E. Wattelet.

(L'Éclairage Électrique, Paris, 1906, vol. xlvii, pp. 401, 441 and 481.)

This Paper is devoted to a discussion of the theory and operation of the synchronizer and of the power-factor indicator constructed by the Thomson-Houston Companies. Each instrument consists of a stator generating a uniform alternating field of fixed direction, and of a rotor revolving in this field, and consisting of two identical circular or rectangular plane disks, permanently fixed at right angles and having a common axis of symmetry which is perpendicular to the direction of the field and forms the axis of rotation of the moving system. The Author bases his discussion solely on the

laws of Laplace on the electro-dynamic and electro-magnetic relations between currents and continuous fields, and deals with his subject under the following heads:—(1) Action of a continuous field on a plane disk; (2) Equivalence between a disk and the field created by it; (3) Action of an alternating field on a plane disk; (4) Problem of synchronizing alternators; (5) Description and construction of the synchronizer; (6) Theory and use of the synchronizer; (7) Rôle of the power-factor; and (8) The power-factor indicator.

W. C. H.

New Type of Arc-Lamp. E. Stadelmann.

(Elektrotechnische Zeitschrift, Berlin, May, 1906, pp. 423–4.)

A poor conductor such as fire-clay, placed close to two arc-lamp carbons in such a manner as to preclude the possibility of its fusing to them or being burnt away, was found to greatly improve the steadiness of the light by acting as a conductor and reflector, as well as an auxiliary source and reserve store of light. The fire-clay may be placed advantageously above and between the two horizontal carbons to throw the light downwards, the arc, after being struck in the ordinary way, impinging on the clay, increasing the illuminating surface and preventing flickering.

C. J. G.

New Induction Watt-Hour Meter. G. Faccioli.

(Electrical World, New York, 1906, vol. xlvii, pp. 1266–8.)

The instrument (invented by W. Stanley) described in this Paper differs from its predecessors in that its operation does not depend on the Ferraris principle of phase-difference. A metal disk is mounted on a shaft so as to pass through the air-gap of an iron core, having a coil wound on one pole. An alternating current passing through this coil gives rise to a magnetic flux in the air-gap and to eddy-currents in the disk, but the torques thus produced are equal on the two sides of the diameter, passing through the centre of the air-gap, so that there is no rotation. A third element is therefore added, consisting of an iron leaf embracing the disk on one side only of the pole, and affording a magnetic circuit of low reluctance to the flux set up by the eddy-currents. The result is a torque proportional to the square of the resultant flux in the air-gap. Such a torque is not proportional to the watts, and therefore to obtain this proportion, two motors of this type are mounted on the same shaft above one another to form a differential system, so that the torques are in opposite directions. The pole of each motor has two coils, a shunt coil and a current-coil. The shunt coils are identical and are

connected in series across the mains, while the current-coils are also connected in series, but so that the main current traverses them in opposite directions. The magnetomotive force of the pressure-coils, owing to their large number of turns, lags behind the electromotive force, while that of the current-coils is in phase with and proportional to the load-current of the circuit. To make the angle between these two the same as the phase-angle of the circuit, the current-coils are shunted by a non-inductive resistance, which may be conveniently proportioned to make the current actually flowing in the series coils of the meter lag behind the load-current by the same angle as that between the current in the shunt coils and the electromotive force. The Author discusses the theory of the instrument, and shows that with this differential system the resultant torque is proportional to the true watts. The apparatus is completed by adding brake-magnets to one of the disks and connecting the shaft to a train of wheels in the usual manner. The results of tests made on many meters of this type are said by the Author to be excellent.

W. C. H.

Iron-Losses in Single-Phase Commutator Motors.

F. NIETHAMMER.

(Electrical World, New York, 1906, vol. xlvii, pp. 612-3.)

The iron-losses in a single-phase commutator motor are affected by two widely-different periodicities, that of the impressed electromotive force and that of rotation, and it is difficult to determine theoretically how the iron-losses depend on them. In this Paper the Author describes experiments made to find the variation of these losses in a single-phase motor with the speed, and gives curves showing the results when the impressed electromotive force had periodicities of 35 and 50 periods per second, and a curve for comparison showing the total iron-losses with direct-current excitation. The curves show that with low speeds the total iron-losses are least for low periodicities, but for high speeds the losses are largest for low periodicities. The curve for 35 periods crosses the curve for 50 periods, and the curve showing direct-current losses cuts first the curve for 35 periods and, later, the curve for 50 periods, the flux remaining constant. The Author states that a knowledge of the character of these curves should be of value where single-phase motors are used for intermittent work requiring frequent stopping and starting, as, for example, for traction purposes on urban lines.

W. C. H.

Heating Effect of Electric Spark. H. A. Perkins.

(Electrical World, New York, 1906, vol. xlvii, pp. 608–9.)

As the spark method of ignition is the most common in all typ of gas-engines, the Author has made experiments to find the exac quantity of heat developed under different conditions, and th efficiency of a sparking-apparatus as a whole, considering the hea developed by the spark as the output and the total power consume by the coil as the input. Three sets of tests were made and ar here described. In one set the spark-length was varied, in anoth the primary current was varied with constant spark-length, and i the third the frequency of interruption was considered the variab quantity. The results show that the heat developed by the spar increases with its length, not as a linear function but yet so as t suggest a rise in temperature as the spark-length increases. Th efficiency increases in the same proportion, and it thus appears tha in a gas-engine the spark-gap should be as long as possible and ye allow the spark to pass during the highest pressure used in the compression stroke. High frequencies are also more effective and mor efficient than low ones. As to voltage, there appears to be a certai critical voltage, its value depending on the coil used, which gives th highest efficiency. The highest efficiency obtained is surprisingl low.

W. C. H.

Electric Traction by Continuous Currents at High Pressure. A. Solier.

(L'Éclairage Électrique, Paris, 1906, vol. ~~xlvi~~ xlvii, pp. 174–8.)

The Author gives a brief description of the equipment of a electric railway connecting Bonn and Cologne,[1] which has bee recently opened and is of interest, in that it affords an examp of the use of high-pressure continuous currents for electri traction. The total length of the line is about 17 miles, and a Bonn and Cologne it connects with the tramway systems of tho towns, which are operated by continuous current at 550 volts. Th system adopted, therefore, is to use continuous currents at 99 volts in the open country and at 550 volts in the towns. The high pressure current is supplied to the trains by a double overhead wir suspended from a cable above the track and well insulated. Th electric lines for signalling, telegraphs and telephones are all i cables underground, so as to avoid perturbations due to variations i the traction current. The rolling stock includes five locomotives fo goods-trains, and ten motor-coaches, with ten trailers for passenge trains. Each train usually consists of two motor-coaches and tw

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[1] See *ante*, p. 404.

trailers and carries, when thus constituted, 258 persons. Each motor-coach has two motors of 130 HP. at 990 volts, revolving at 700 revolutions per minute. The axles are driven through gearing. Each motor has four poles with auxiliary poles to ensure sparkless commutation at all loads and under all conditions of working. The Author describes the construction of these motors, giving dimensions of parts, arrangement of brushes, and general arrangement to economize space. The multiple-unit system of control is employed on the trains.

W. C. H.

Electric Traction in the Simplon Tunnel. A. SOLIER.

(L'Éclairage Électrique, Paris, 1906, vol. xlvi, pp. 456–8.)

It was originally intended that steam locomotives should be used on the railway through the Simplon tunnel, but owing to difficulties of ventilation it was finally decided, near the end of 1905, to equip the line for electric traction and to use electric locomotives of about 1,000 HP. As the line had to be open for service in the spring of 1906, there was no time to make a special study of the problem and design locomotives of a new type, and it was decided to adopt three-phase locomotives similar to those recently constructed for the Valtellina line. Two locomotives to supply the service from the 1st June, 1906, were therefore constructed by Messrs. Brown, Boveri and Company, and the present Paper contains an illustration and description of these engines. Each locomotive has three driving-axles and two trailers, which form bogies with the extreme driving-axles. Two three-phase motors are mounted on the chassis between the axles and drive the axles by cranks and two coupling-rods; there are no gear-wheels. The two motors, arranged for grouping in cascade with two secondary motors, give two speeds of about 40 and 20 miles per hour. The weight of the locomotive is 61 tons, that of a passenger-train about 360 tons, and of a goods-train about 458 tons. The line in the tunnel has gradients reaching 1 in 10 for short lengths; further, the northern part, from Brig to the middle of the tunnel, has a continuous slope of 7 per cent., and the southern part, from the middle of the tunnel to Iselle, has a continuous slope of 2 per cent. For passenger-trains the journey from Brig to Iselle is expected to take 20 minutes; in the other direction, 30 minutes; and for goods-trains, 40 minutes in either direction. Current is supplied to the locomotives from two overhead copper wires suspended from transverse wires fixed to studs cemented in the walls. The rails supply the third conductor and are therefore bonded. At the middle of each tunnel there is a loop on the line to allow trains to pass, if necessary. This loop is equipped for electric traction, and at its ends there are interrupters which allow of the subdivision of the contact wires in the tunnel. The three-phase currents are supplied at a pressure of 3,300 volts, frequency 15 periods per second, from two

water-power generating-stations, one at Brig and one at Iselle. These stations were in use during the construction of the tunnel to supply current to the numerous machine-tools and engines in operation and they are able to supply all the power required so long as the electric traction is confined to the tunnel portion of the railway. At a later date electric traction may be extended on the railway both on the Italian and on the Swiss side of the tunnel.

W. C. H.

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Atmospheric Electricity and Trees. A. G. McAdie.

(Electrical World, New York, 1906, vol. xlvii, pp. 870–4.)

In this Paper the Author summarizes the investigations which have been made on the effect of sunshine on wireless messages, the absorption of electromagnetic waves by trees and living vegetable organisms, and the behaviour of trees during thunderstorms. The Paper closes with the description of a series of experiments, made by the officer in charge of the Weather Bureau station at Mount Tamalpais, U.S.A., and bearing mainly on the conductivity of freshly cut trees, made to form part of the antenna for receiving wireless messages.

W. C. H.

Production of Red Light in the Mercury Lamp.

E. Jehrcke and O. von Baeyer.

(Elektrotechnische Zeitschrift, Berlin, April, 1904, pp. 383–7.)

The light emitted by the type of mercury lamp usually employed differs widely from that customary in other sources of light, inasmuch as its spectrum is devoid of red lines. Previous attempts to remove this obstacle to the extensive use of the lamp, such as the addition of red fluorescent bodies,[1] or glow-lamps, were only partially successful.

The Authors found that with an electrode consisting of an amalgam of 100 parts of zinc to 30 parts of mercury, together with a little sodium metal, the character of the light emitted was very much akin to that of the "Bremer" arc-lamp.

A lamp-casing of amorphous quartz was employed, current being supplied at 110 volts through a resistance. The addition of a trace of bismuth was found advantageous to obviate cracking of the lamp-casing from expansion of the amalgam, the character of the light at the same time remaining practically unchanged.

C. J. G.

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[1] M. von Recklinghausen, *Elektrotechnische Zeitschrift*, vol. xxiii (1902), p. 495.

Measurement of High Temperatures. E. Ballois.

(L'Éclairage Électrique, Paris, 1906, vol. xlvi, pp. 484–92.)

This Paper contains a description of the different methods employed for the precise measurement of high temperatures and of the construction of instruments typical of each method. Apparatus of the thermometric type is first considered, one of the examples given being the apparatus devised by Saintignon, in which a double metallic tube, placed in the furnace the temperature of which is to be measured, is traversed by a current of water at a known speed, and the difference of the temperature of the water on entering and on leaving the tube, measured by two thermometers, gives the temperature of the furnace. This apparatus may be used for all temperatures between 0° and 2,500° C. The second class of pyrometer considered is the thermo-electric type, the development of which is due to Le Chatelier, who showed that excellent results could be obtained by using thermo-electric couples of certain metals, such as platinum and its alloys with rhodium or iridium. The Author explains the construction of several instruments of this class, viz., those of Ducretet, Chauvin and Arnoux, Carpentier, Crompton, and Siemens and Halske; and shows how they are standardized and the different methods by which the electromotive force of the circuit containing the couples may be measured. This class of pyrometer is open to the objection that by repeated exposure to the heat of a furnace the physical properties of the metals forming the couple may be altered, and to avoid this trouble a type of pyrometer has been devised in which the couple is not exposed to the furnace, but has the rays from the furnace or incandescent body concentrated on it by means of a lens or telescope. An example of this type is the Féry pyrometer, in which the temperature of the thermo-couple is never raised above 80° C., while the instrument can measure temperatures ranging between 500° and 1,100° C. in one model, and between 900° and 3,500° C. in another. Each of these models is described and illustrated. The last class of pyrometer considered by the Author is that which allows direct observation of the luminous shade of an incandescent body, or comparison of a monochromatic band of the spectrum of the body with a monochromatic band from a standard source and corresponding to the wave-length. The instrument devised by Mesuré and Nouel is described and illustrated as an example of the first category, and the Féry absorption pyrometer is taken as representative of the second.

W. C. H.

Photometry of Tantalum Lamps. C. H. SHARP.

(Electrical World, New York, 1906, vol. xlvii, pp. 1249–50.)

In the photometry of the ordinary carbon lamp the mean spherical candle-power is obtained by measuring the mean horizontal candle-power, and multiplying by a "spherical reduction factor," which has substantially the same value for all lamps of the same type. It is not *primâ facie* evident that this method is not applicable to the tantalum lamp, but, as the result of tests, the Author has found that the spherical reduction factor for tantalum lamps is by no means constant, but varies considerably from lamp to lamp, and varies for the same lamp with age, in one case to as much as 30 per cent. of the initial value. The total light emitted in the horizontal plane becomes smaller and smaller as the lamp ages, yet the mean spherical candle-power may even be increased, and this fact shows that tests of tantalum lamps, to be reliable, must be based on readings of mean spherical candle-power. The change in the spherical reduction factor is accompanied by a change in the distribution of the intensity of the light in a vertical plane, caused mainly by a localized blackening of the bulb on those parts of the glass which are parallel to the filaments, and nearest to them, and also by a roughening of the filament through use, resulting in a relative increase of radiation in directions not at right angles to the filaments.

In determining the mean horizontal candle-power of the carbon lamp, it is usual to rotate the lamp on the photometer at 180 revolutions per minute, but this procedure cannot be adopted with the tantalum lamp, as that speed of revolution is found to cause the vertical spires of the filament to curve outwards perceptibly, resulting in a change in the vertical distribution curve of the lamp. One way to obviate this difficulty is to reduce the speed of revolution to 40 revolutions per minute, when this bending effect is no longer apparent; or some form of spherical integrating photometer may be used, but even where this method is adopted, it is better to reduce the speed of revolution to the lowest practicable limit.

W. C. H.

Production of High Vacua by Use of Liquid Air.

G. CLAUDE and R. J. LÉVY.

(Comptes Rendus de l'Académie des Sciences, 1906, vol. cxlii, pp. 876–7.)

Taking advantage of Dewar's discovery of the active absorption of gases by carbon at the temperature of liquid air, the Authors have devised an apparatus for the production of very high vacua. The vessel to be exhausted is placed in communication with a pump and with two or more vessels containing carbon and constructed for

immersion in liquid air. By means of the pump a partial vacuum is produced in all the vessels; the pump is then disconnected and one of the carbon vessels is immersed in liquid air, thus lowering still further the pressure in the other vessels. The immersed vessel is then cut out of the circuit, and the next one immersed. The same process is repeated as often as is necessary, but in practice two vessels with carbon are sufficient to give the highest vacuum actually obtainable. These vessels are put in, or cut out of, circuit by means of mercury columns controlled by plunger pistons or by atmospheric air, and to eliminate the mercury vapour the mercury is cooled by liquid air near the tops of the columns.

W. C. H.

Prismalithe. COPPIN.

(Bulletin de la Société d'Encouragement pour l'Industrie Nationale, Paris, 31 May, 1906, pp. 501-2.)

A report is presented by Mr. Larivière to a Committee of the Society on an invention by the Author. It is well known that when magnesia is sprinkled with a solution of magnesium chloride a paste is formed which solidifies in the course of a few hours; the induration is caused by the production of a hydrated magnesium oxychloride. If sawdust or tow is mixed with the magnesia a material is obtained which possesses properties intermediate in character between those of wood and stone. It can easily be worked and is a bad conductor of heat, it is almost incombustible and cannot readily be bent, crushed or worn away by friction. These qualities have secured its employment for many structural purposes to which reference is made, but certain difficulties have arisen in its use which the Author's process tends to obviate. By his system the mixture in question, which is mechanically prepared with suitable apparatus, is subjected to heavy pressure in moulds to produce blocks or slabs of the so-called "prismalithe." The slabs are made 3 feet 3 inches square and in various thicknesses, starting with 0·39 inch. The compressed stone prepared in this way is said to be very homogeneous and to possess in a high degree the properties already mentioned as belonging to this material when made by hand. The blocks, which can be sold at a price of 9*d.* to 10*d.* per square foot according to thickness, are set and jointed with a mortar composed of the same substance.

G. R. R.

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TO THE

MINUTES OF PROCEEDINGS,

1905–1906.—Part IV.

N.B.—Titles in italics refer to Original Papers, those selected for printing only *being further distinguished by the suffix* "(S.)". *Abstracted Papers are not so* *indicated.*

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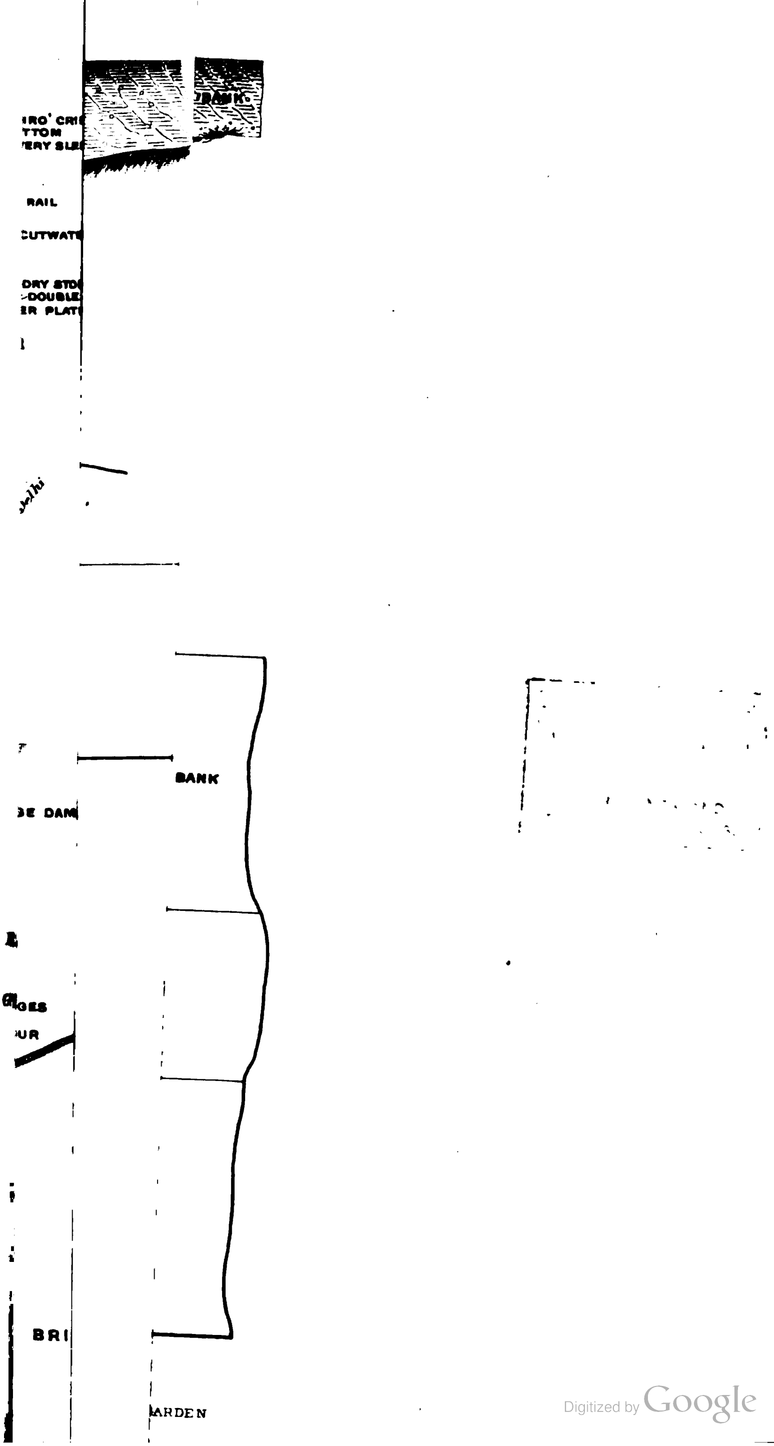
PLATE 3.



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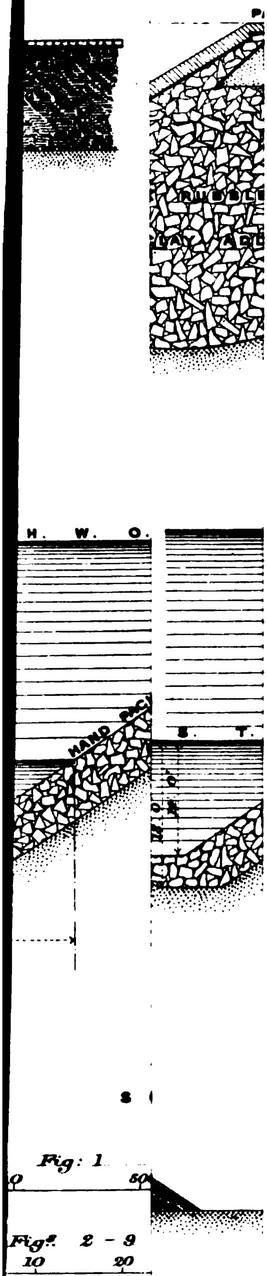

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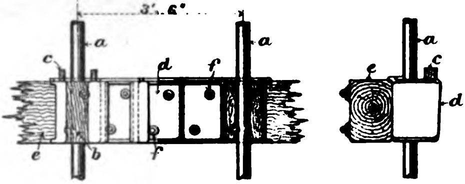

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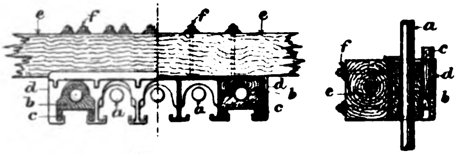

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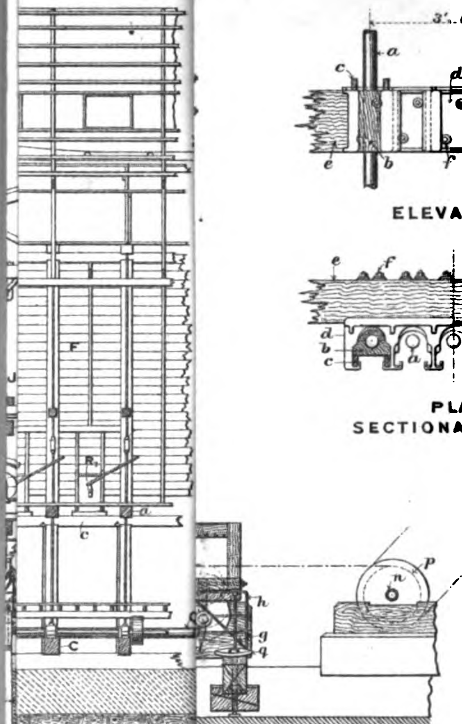

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Inches 12 6
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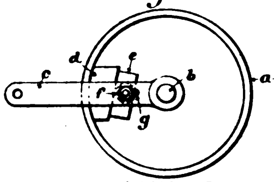
Figs 31.



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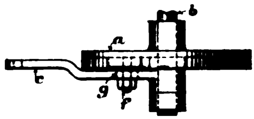

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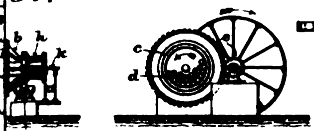

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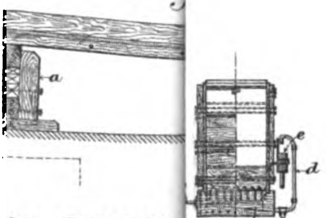

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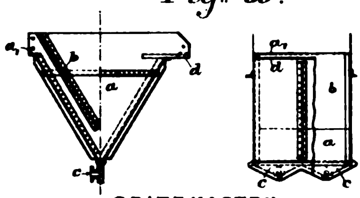

SPITZKASTEN.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

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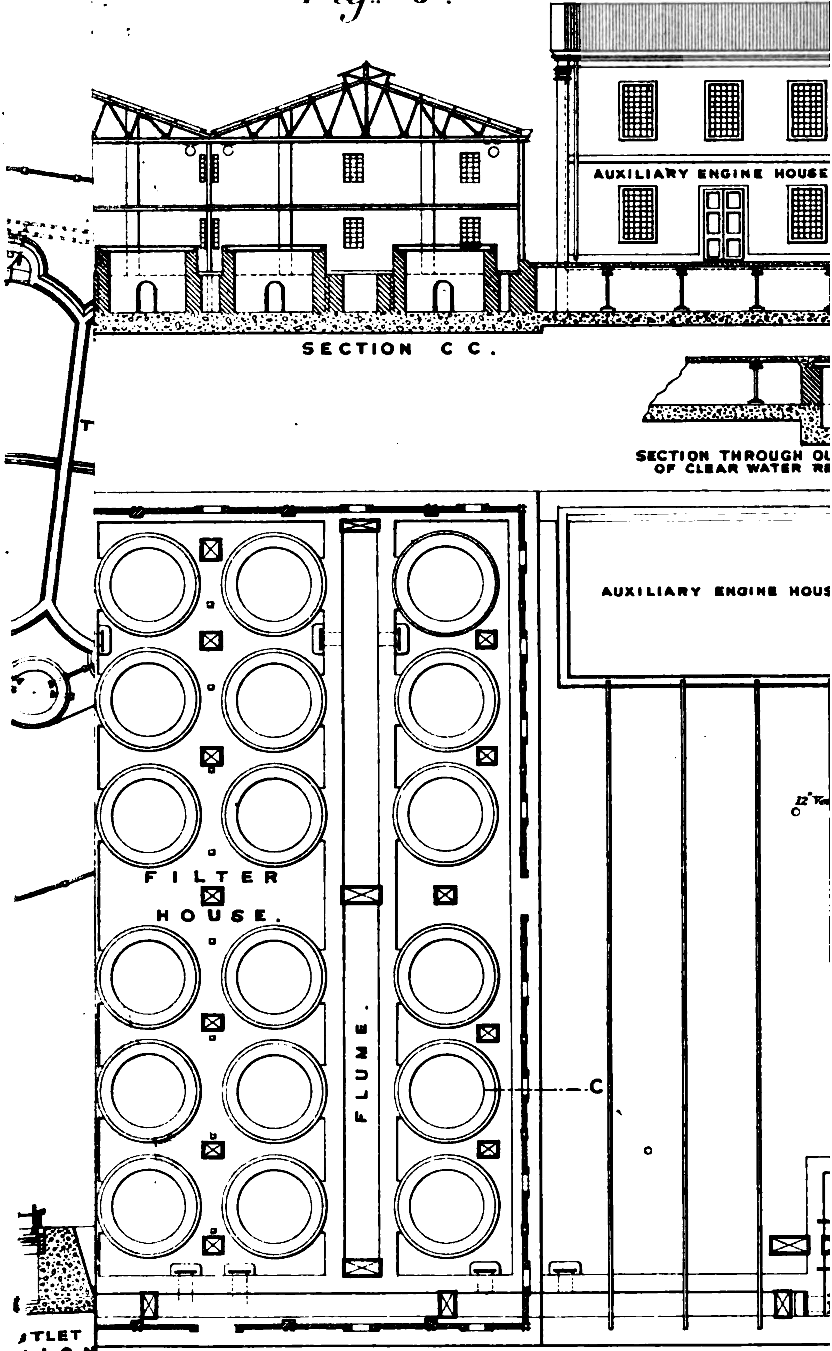

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FILTER-HOUSE AND AUXILIARY ENGINE-HOUSE.

THOS KELL & SON, LITH 40 KING ST C

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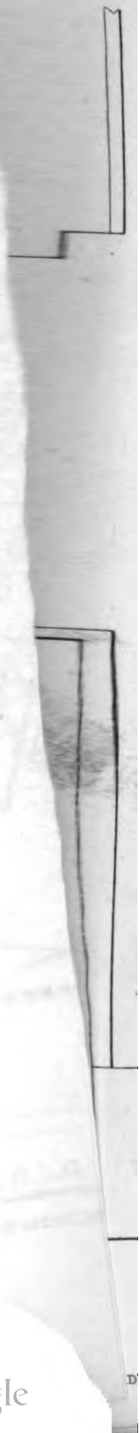

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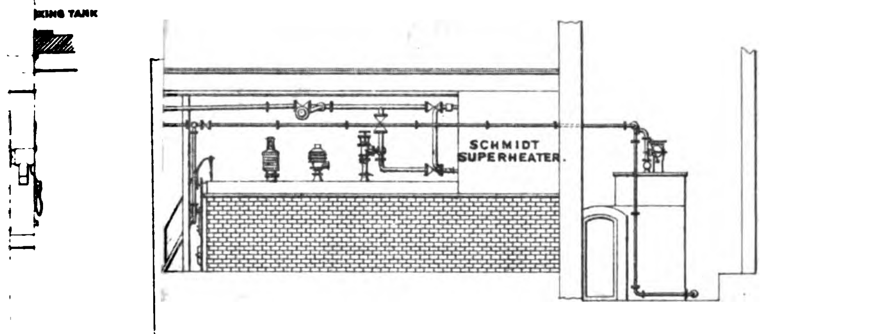

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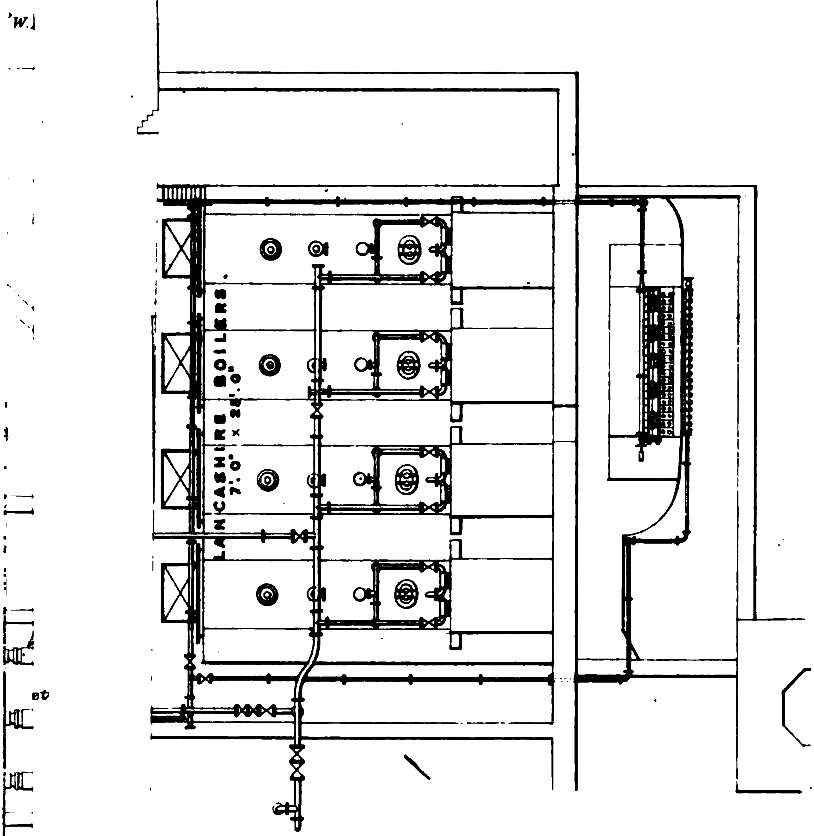

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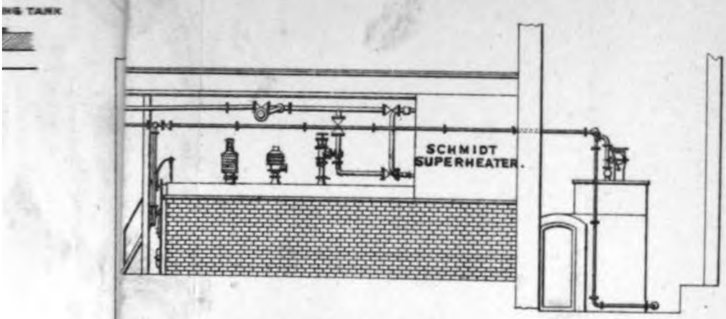
THOS KELL & SON, LITH. 40 KING ST COVENT GARDE[N]



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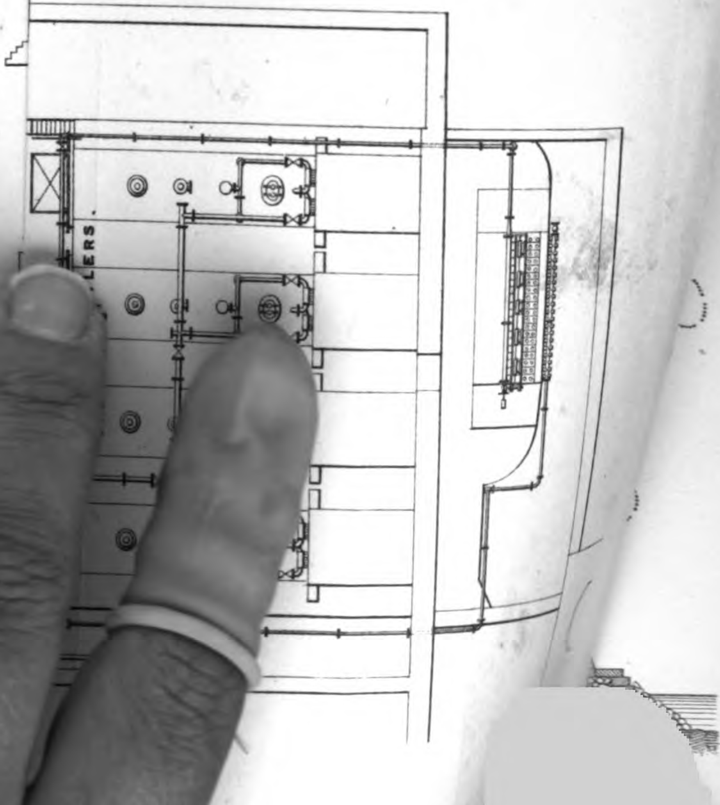
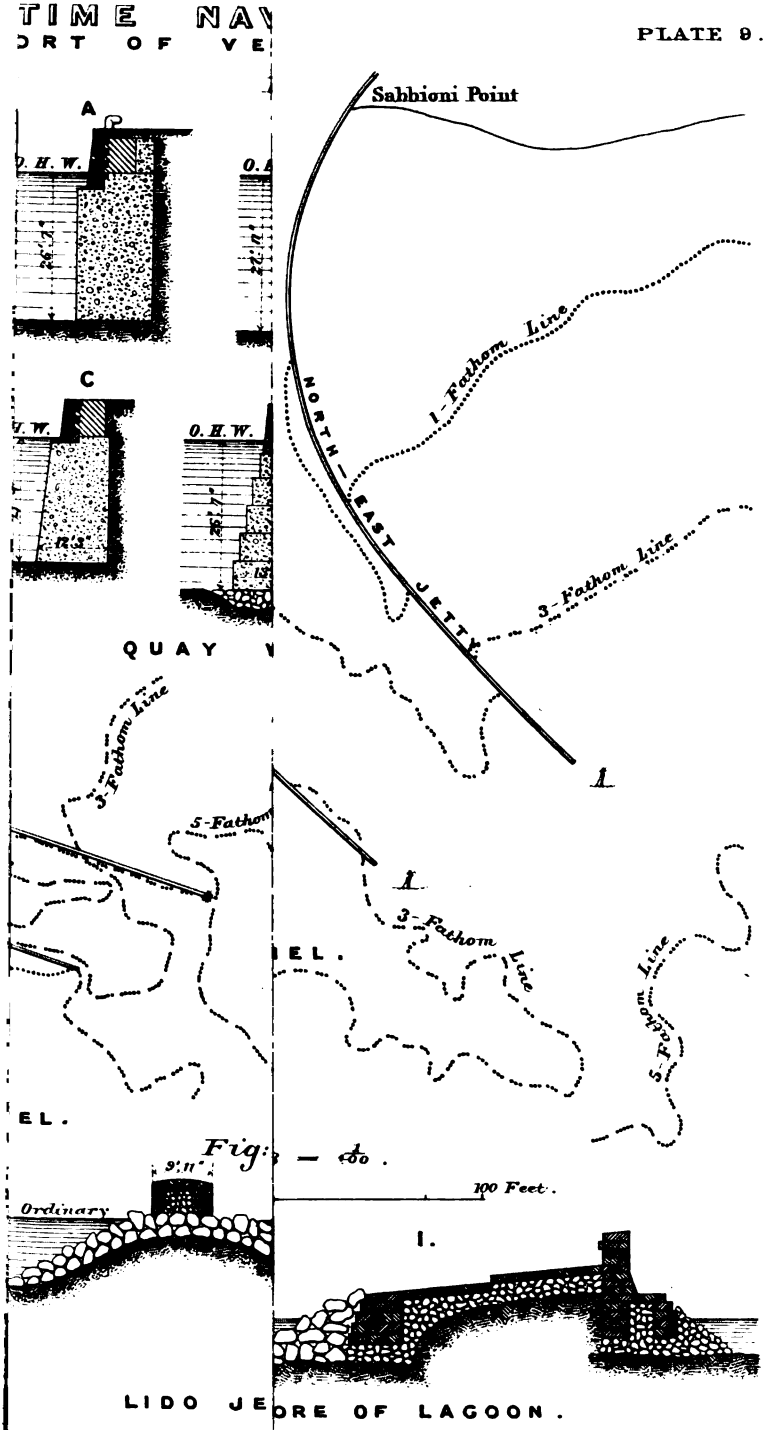


THOS. KELL & SON, LITH. 40 KING ST.

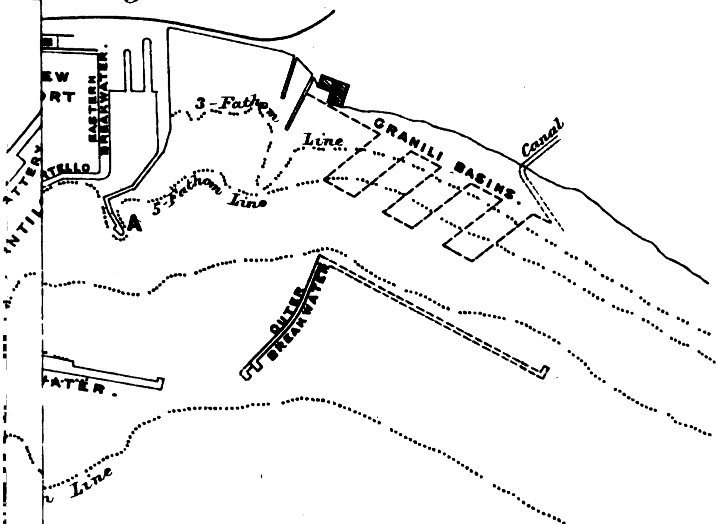
PLATE 9.



titution of Civil Engineers

THOs KELL & SON, LITH 40 KING St COVENT GARDEN

Fig: 18.



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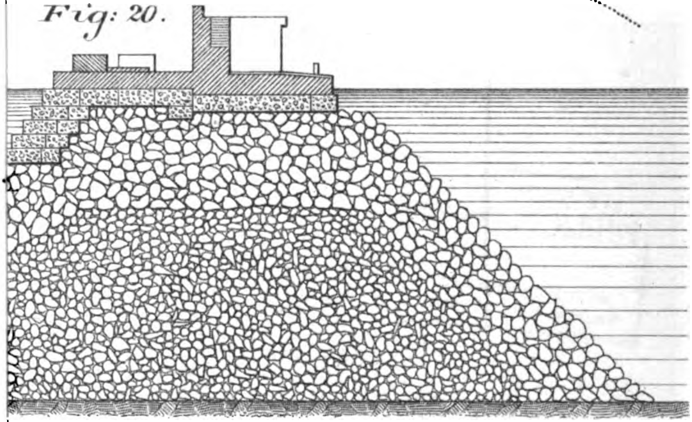

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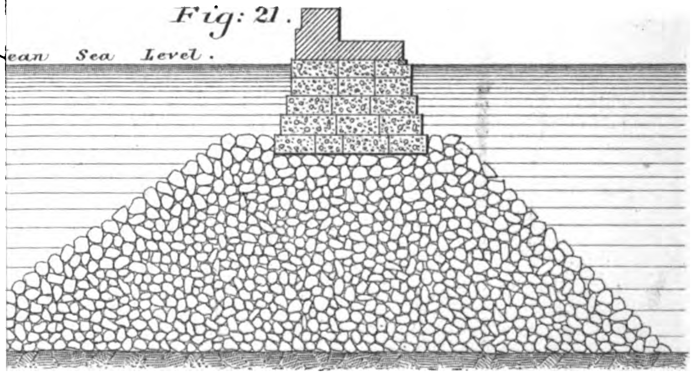

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